CANADIAN AERONAUTICAL INSTITUTE

CANADIAN AERONAUTICAL JOURNAL

Publications Committee:
Mr. R. J. Templin
G/C R. M. Aldwinckle
Mr. F. H. Buller
Mr. J. A. Dunsby
Mr. J. J. Eden

Editor: Mrs. G. G. Ross

Subscription—$4.00 a year. Single copy—50 cents.

Published monthly, except in July and August.

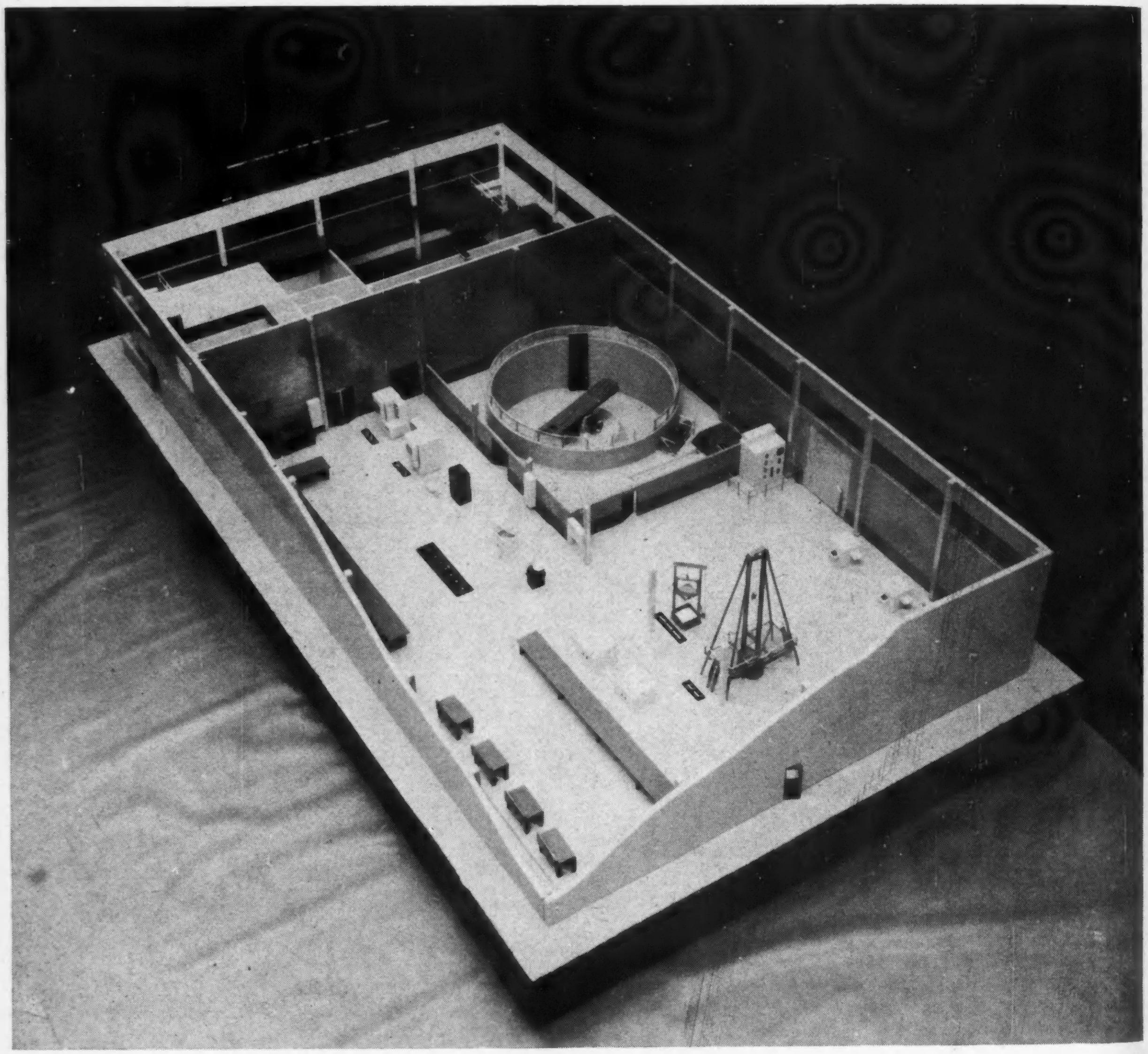
The Institute is not responsible for statements or opinions expressed in papers or discussions printed in its publications.

All communications should be addressed to The Secretary, Canadian Aeronautical Institute, 77 Metcalfe St., Ottawa 4, Ontario, Canada.

Authorized as second class mail, Post Office Department, Ottawa

Printed by The Runge Press Ltd., Ottawa, Ontario, Canada

SERVICE EXPERIENCE IN ADVANCE



Cut-away model of Canadair's new environmental laboratory

EDITORIAL

TOWARD A SPACE PROGRAM FOR CANADA

LAST August a committee headed by the British Interplanetary Society was formed to assess the possibilities of a Commonwealth space program. The idea appears to be to provide a third contender alongside the United States and the U.S.S.R. The limitations of the U.K. and of Canada individually, both in scientific and economic capacity, are thought to be circumvented by means of such a Commonwealth-wide effort. The idea is an attractive one and appeals strongly to Canadian sentiment. It has already had some repercussions in the Canadian press. But the glamour of the notion may diminish somewhat in the face of practical considerations.

Firstly, there is the suspicion that the economic capacity of the Commonwealth might be sorely burdened by a go-it-alone space program. Canada's current reappraisal of its air defence policy supports this suspicion. Even if the cost per satellite launching – successful or otherwise – were no more than the three million dollars suggested (according to reports) by Dr. Dryden, Deputy Director of the U.S. National Aeronautics and Space Administration, the cost of a program in conjunction with the supporting services would be extremely high.

Secondly, geography is against the Commonwealth plan. Traditionally Canadian aeronautical research and development has been interwoven more closely with the American scene than with the British. This started with J. A. D. McCurdy and the Silver Dart and has extended to the present time. For example, models of the Arrow were extensively tested in a number of U.S. wind tunnels; the Iroquois was exhaustively tested in the N.A.C.A. Lewis Flight Propulsion Laboratory; technical consultations were held as needed on both sides of the border. All this has been largely a matter of physical propinquity.

As a potentially workable alternative to a Commonwealth program, therefore, I would suggest Canadian-American cooperation in a single space endeavour with Canadian overtones. The single space program is, of course, the U.S. enterprise already under way. The overtones would arise from a supplementary Canadian effort of appropriate scope; an extension of the present IGY activities and the additions of others. Under U.S. law, Canadian firms may already compete with American firms for defence contracts. This policy and its administration should be broadened by negotiation to permit Canadian firms to compete, even as prime contractors, in the United States space program.

An augury for a more favourable atmosphere within the United States may perhaps be inferred from the appointment of Henry E. Billingsley in January to fill the newly created position of Director, Office of International Cooperation in the National Aeronautics and Space Administration. "He will coordinate NASA's research and development programs with those of other nations and international organizations" (*Aviation Week*, Jan. 12, 1959). If its function is correctly stated, the new Office should serve as a point of contact for Canadian interests.

Dr. G. N. Patterson's proposed National Committee for Space Technology (*Canadian Aeronautical Journal*, Sept. 1958), if created, could provide a starting point for the implementation of these ideas. It could organize the supplementary Canadian space program, "advis(ing) engineers and scientists of the areas where research and development might be attempted". It could present concrete proposals to the government. And, finally, by coordinating the overall Canadian space effort, it could maintain a degree of autonomy even though that effort were integrated with the American program.

DR. H. S. RIBNER,
Chairman, Astronautics Section

SERVICE EXPERIENCE IN ADVANCE

THE designer, manufacturer and purchaser of a product have a common interest in its performance and reliability under the conditions which may be encountered during its working life. As equipment becomes more complex, with increasing numbers of functional components, and as operating conditions become more severe, economical methods of providing advance assurance of satisfactory service are required. In many fields, it is no longer tolerable to endure equipment failure or sub-standard performance for the extended period of time necessary to establish corrective measures based on service history.

Figure 1
Canadair's new environmental laboratory building

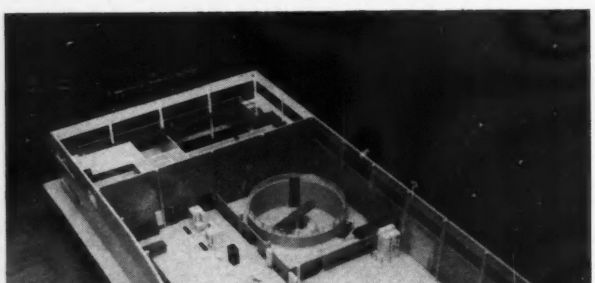


Figure 2
Cut-away model of environmental laboratory

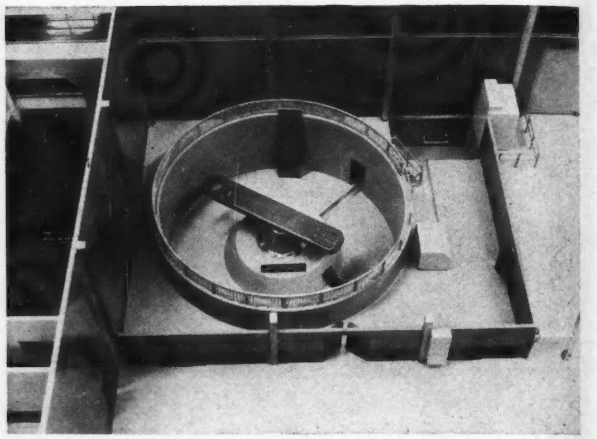


Figure 3
Model of centrifuge installation

The increasing demand for environmental testing is the outcome of recognition of the immense savings in time and material which result from the rigorous prequalification of new and modified designs in advance of large-scale production and service experience. Through component and assembly evaluation testing and the analysis of modes of failure, the designer acquires vastly improved control over the end product. Qualification and acceptance tests to standard or special specifications provide the essential assurance of serviceability.

To meet the growing need for fully equipped environmental facilities capable of serving industry, educational institutions, research establishments and government agencies, Canadair has built a new, specially designed laboratory, shown in Figure 1, to house its environmental work. The building is now complete and will be in full operation by April, 1959.

Testing capability covers climatic conditions, vibration, shock, and acceleration. An equipment layout model is shown in Figure 2. Supporting facilities include laboratories specializing in instrumentation, hydraulics and pneumatics, and test equipment development, plus model shops and a standards laboratory. Among the advanced features of the laboratory are a centrifuge with a radius arm of 12 ft, shown in model form in Figure 3, and a refined data tape system for data reduction, playback and transcription for automatic programming.

Through evaluation testing for selection of components, development testing to determine serviceability and design weaknesses or limits, and qualification testing to specifications, an environmental laboratory provides practical and economical solutions to the problems of quality and reliability in development and production.

P. JACKSON
Canadair Limited

THE ROLE OF ELECTRICAL ACTUATING SYSTEMS IN SUPPLEMENTING SEAMASTER FLIGHT CONTROLS†

by H. C. Zachmann*

The Martin Company

INTRODUCTION

THE Martin SeaMaster (Figure 1) is a large aircraft of some 160,000 lb gross weight, having a speed of over 600 mph. The primary flight control systems are all actuated by hydraulic cylinders. A stabilizer-elevator combination is used for longitudinal control. Four spoilers arranged in groups consisting of inboard and outboard pairs are located on the wings for lateral control, and directional control is accomplished by a rudder. Hydraulic position type servos are located near each control surface and are connected by cables to the appropriate control column, control wheel, or rudder pedals in the cockpit. Proportional control is attained since the positions of the surfaces are fed back to their respective control valves by a mechanical system of push rods and bell cranks. These flight controls are not unusual for an aircraft of this type. They employ a simple and reliable mechanical-hydraulic system. However, the wide performance range of the aircraft requires that the control surfaces be fully powered and irreversible. Since this type of powered system does away with feedback of aerodynamic forces to the pilot, it is necessary to generate the feedback forces artificially by the various feel systems. This is done by electro-mechanical actuators applied in a novel manner, so that the pilot has the benefit of artificial feel in the three major flight control systems for control surface position and airplane q.

HYDRAULIC SYSTEMS

The power actuating motivation is performed by the various hydraulic systems. Therefore, a brief discussion of the various independent systems and their functions in regard to flight controls follows.

There are four independent 3,000 psi hydraulic systems which, among other functions, are used in conjunction with the flight control systems. Eight identical engine-driven and one motor-driven variable volume pumps are arranged in a manner so that neither system is supplied wholly from pumps driven by one engine. For instance, three pumps located on three engines supply the No. 1 surface control system, which operates the inboard spoilers and the stabilizer-elevator. In a similar manner, three pumps supply the utility system which operates the stabilizer-elevator, wing flaps, rudder, and the hydro flaps/speed brakes. The No. 2 surface control system operates the outboard spoilers as well as the stabilizer-elevator and is supplied by two engine-driven pumps. The motor-driven pump supplies the utility and emergency system, which operates the wing flaps and mine door.

Figure 1
Martin SeaMaster

The electric-motor-driven pump is powered by a 19 hp intermittent duty or 12 hp continuous duty motor. The motor normally operates from the main 400 cycle power supply consisting of two 40 KVA, 400 cycle alternators operating in parallel. Close control was maintained over allowable motor inrush current because of the long wire run needed to reach the motor-pump unit in the mine loading compartment of the airplane, and the limitation imposed by the maximum size of available circuit breakers. The motor can be started in flight from a two-generator parallel system operating under normal flight loads without unduly shocking the power system. However, under single generator operation or APU operation a large voltage dip of short duration is experienced. The motor is equipped with a new type of thermal protector which permits

†Paper read at the Joint I.A.S./C.A.I. Meeting in Ottawa on the 8th October, 1958.
*Staff Engineer, Electronics and Electrical Dept.

maximum operation of the motor almost to the point of failure before the protector removes it from the line.

DIRECTIONAL CONTROL SYSTEM

The rudder is activated by a single hydraulic cylinder connected through a bell crank and push rod arrangement. As previously mentioned, the rudder is powered from the hydraulic utility system. The hydraulic cylinder is undersized in that it will not develop sufficient force for full rudder deflection at high speeds. This in no way limits the maneuverability of the airplane as sufficient power exists for any proper maneuver or asymmetric power condition at any speed. Should the feel system fail at a low speed condition the cylinder is sized such that it prevents the pilot from using too much rudder at high speeds. Should the hydraulic system fail, the rudder can still be operated directly through a mechanical linkage. Although the forces may be high, they can be relieved somewhat by means of the trim actuator. Figures 2 and 3 depict in schematic and trimetric form the directional control system and the feel and power unit, respectively.

The rudder control system is composed of one cable circuit and a single feel system. The feel system is a type wherein the stick force is proportional to q (dynamic air pressure) and Δ (rudder deflection from trim). The feel system uses a torque tube as a torsion spring to provide the force. The proportionality with Δ is obtained by making the spring deflection proportional to the rudder deflection. A permanent magnet 28v dc motor irreversible acme screw actuator with internal limit switches but without thermal protector or motor brake is used as a push rod, thus allowing the pilot to shift the null position of the rudder control system to trim the airplane. The choice of this type of actuator presents a flat rate characteristic regardless of external loads, whether positive or negative. It is discussed more fully in "Design Parameters for Airborne Electric Motor Actuators," AIEE Paper CP 58-833 by H. C. Zachmann. Figure 4 from the referenced paper depicts this characteristic over a wide load range. Ultimate strength and vibration requirements of primary structure also apply to the actuator at any stroke position since the actuator mechanically is considered as a push rod. The actuator is rated at 170 lb load at a rate of 0.145 in/sec with a speed tolerance of $\pm$ 25% over a load range of 0 to 170 lb aiding load. Actual performance experienced is much better than the allowable specification. Electrical stroke is 2.125 inch.

The proportionality with q is obtained by using a bell crank with an arm length which is varied proportionally to the $\sqrt{q}$. Note on Figure 2 that the q actuator moves a trunion in a slot which moves in an arc and is connected to the feel torsion spring push rod which turns at a constant radius. Thus the q actuator does not crank additional trim into the system with movement as will be discussed later under stabilizer feel system. A pressure transducer in the pitot-static system is connected in series with a variable potentiometer in the q actuator, which is balanced in a bridge incorporating additional potentiometers in the actuator (similar to Figure 5). The signal of the transducer is proportional

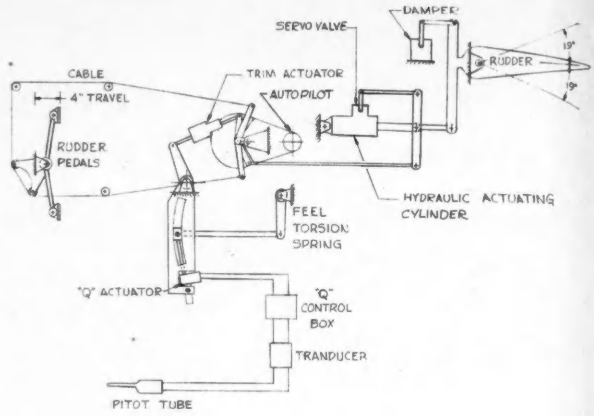


Figure 2
Schematic of directional control system

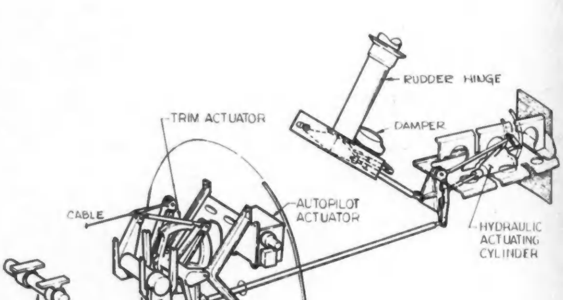


Figure 3
Trimetric of directional feel and power unit

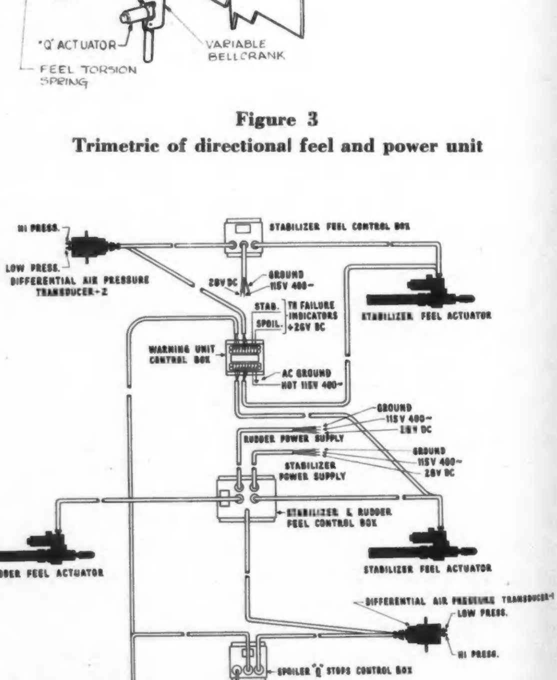


Figure 4
Actuator system responsive to q

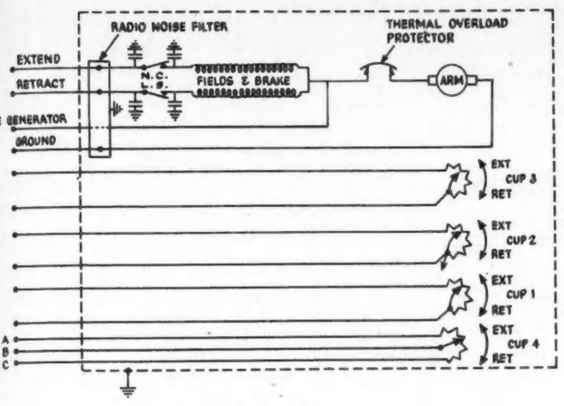


Figure 5
Schematic stabilizer q actuator

to the $\sqrt{q}$. The control box in turn automatically positions the actuator to vary the torque arm in the feel system so that the force felt at the rudder pedals varies as q. The rudder q actuator is a 28v dc, consequent pole, series-wound actuator. It is of the irreversible acme screw type with a motor brake and thermal protector and internal limit switches. The potentiometers are externally adjustable for system coordination with the transducer and control box elements. Actuator or power failure holds the q system at the established rate at the point actuator or power failure occurred. The actuator has a stroke of 8.9 inch and a rating of 200 lb at 0.21 in/sec, 400 lb at 0.11 in/sec.

RUDDER GUST LOCK SYSTEM

A rudder gust lock, mounted in the hull below the rudder, is pilot controlled and electrically operated by a switch assembly in the pilot's pedestal. The switch is mechanically interconnected with the engine power levers so that they cannot be moved out of idle when the rudder gust lock is engaged. Turning the switch to lock energizes a 28v series-wound actuator with internal position limit switches which engages the rudder gust lock after the rudder is held in the neutral position.

LATERAL CONTROL SYSTEM

Because aileron effectiveness, like that of elevators, decreases at high speeds, the SeaMaster uses spoilers for lateral control. Each wing has two systems of spoilers with a corresponding cylinder and valve. The inboard spoilers are connected to the No. 1 hydraulic flight control system; the outboard to the No. 2 system. The cable circuits are duplicated and so arranged that two circuits have to be broken before any spoiler becomes disconnected from the control system.

A schematic of the lateral control system is shown in Figure 6. A q failure warning system, also incorporated in the system, is not shown. The feel system provides a feel force which is directly proportional to spoiler deflection. A series wound 28v dc motor actuator, as shown in Figure 7, is attached to the end of the feel spring. Actuation of the actuator allows the pilot to shift the null point and thus trim the lateral control system. The actuator has an electrical stroke of 2.83 inch and is rated at 75 lb aiding load at 0.25 in/sec. Since the actuator is of the irreversible acme screw variety, the same comments as were made for the rudder trim actuator apply in this case also.

The feel system for the spoilers differs from that of the rudder and stabilizer in that while it is mandatory to consider the effect of q on spoiler operation, q is recognized not as a force on the control wheel but as an adjustable stop that limits travel of the wheel. The system has a set of adjustable stops, shown in Figure 6, operated by an electrical actuator which limits the maximum allowable spoiler deflection from trim as a function of q. Again a pressure transducer converts the dynamic pressure to a voltage and a control box positions the actuator according to the value of the voltage or q. In addition a comparison bridge circuit is incorporated in the control box which compares the voltage of the transducer with a follow-up voltage derived from the actuator which, in effect, proves that the actuator has achieved the correct position in regard to q.

Should the actuator fail for any reason electrically or mechanically an error signal is produced which oper-

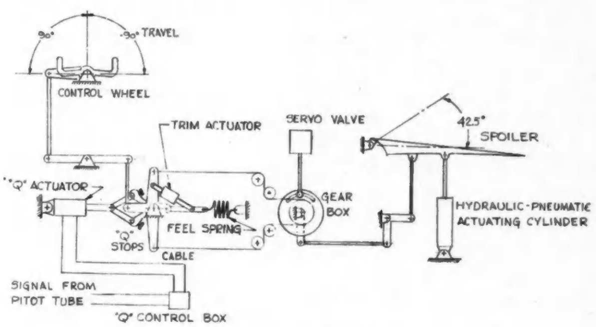


Figure 6
Schematic of lateral control system

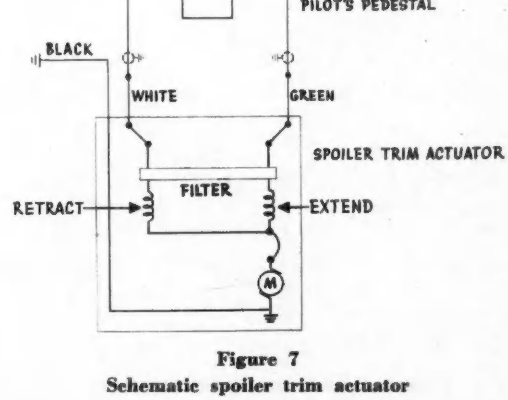


Figure 7
Schematic spoiler trim actuator

ates a q failure warning light on the engine instrument subpanel, informing the pilot that the q system is not functioning. Accordingly, speed and maneuvers must be monitored immediately. There is a mechanical release mechanism to be used in case of a malfunction of the q system. However, precautions must be observed in operating with q stops released, since the stops prevent high rolling rates at high indicated airspeed which would impose severe torques on the hull afterbody. The spoiler q stop actuator is a 28v dc, series-wound, consequent pole type with motor brake and thermal protector, but without stroke limit switches. Any malfunction of the control box to stop the actuator would be handled by the mechanical stops of the actuator and the thermal protector. The q failure warning unit would advise of actuator malfunction under these conditions, and the mechanical release could be used for spoiler control. The actuator is rated at 200 lb load at 0.25 in/sec minimum.

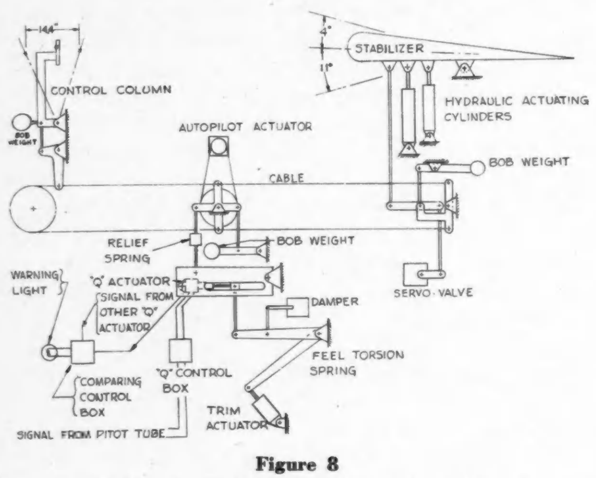


Figure 8
Schematic of longitudinal control system

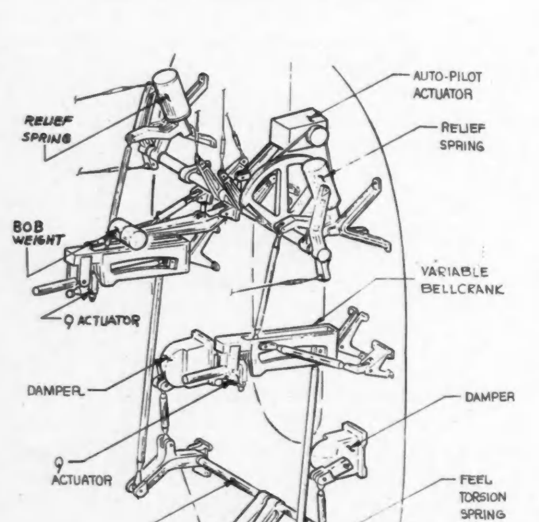


Figure 9
Trimetric of longitudinal feel system

LONGITUDINAL CONTROL

The longitudinal control problems required the utmost effort to provide a satisfactory system for the wide performance range of the SeaMaster. The airplane is equipped with a flying tail stabilizer-elevator combination which is found in many high speed aircraft, primarily because elevator effectiveness decreases at high Mach numbers. In addition, any tendency for the elevator to flutter is also eliminated. Three hydraulic systems, each with its own valve and cylinder, supply power to operate the stabilizer. Dual cable systems connect the control columns to a triple hydraulic servomechanism in the fin of the airplane. The servo consists of three mechanically connected and synchronized control valves, dampers, hydraulic actuators and a mechanical follow-up linkage for proportional control, as shown in Figures 8 and 9. The No. 1 and No. 2 flight control hydraulic systems operate a tandem cylinder and the utility system operates a completely separate cylinder.

The sole function of the elevator is to provide the additional tail power necessary for landing and takeoff. There are two modes of elevator operation — locked or slaved. As the name implies, in the locked position, which is used for all flight conditions except wing flaps down, the elevators are locked to the stabilizer and the two controls move as a continuous surface. In the slaved position, the elevators are actuated by the stabilizer through a system of push rods and bell cranks, so that when the leading edge of the stabilizer is in the full up position the elevators are faired with the stabilizer, and when the stabilizer leading edge is full down the elevators are maximum upward (30°) from the stabilizer chord. Figure 10 depicts the mechanical linkage and the electric actuator which changes the mode of elevator operation.

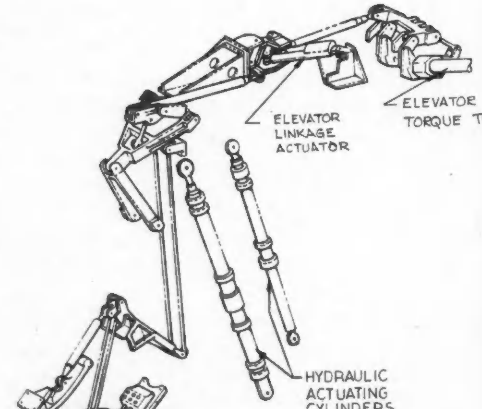


Figure 10
Trimetric of elevator and stabilizer controls in fin

The change in mode of operation is performed by a 400 cycle electric actuator. It requires from 15 to 25 sec, depending on loading and takes place with very little trim change connected with the transition. Figure 11 shows an electrical schematic of the elevator lock actuator system. In brief, the electric actuator is energized through a relay and a limit switch located on the wing flap interconnect so that the elevator is automatically slaved as the flaps extend. A bypass switch is also provided so that the elevator can be slaved for the initial part of the takeoff run before wing flaps are extended. However, the flap switch must be in the neutral position to accomplish this mode. With wing flaps up the actuator again automatically locks the elevator to the stabilizer.

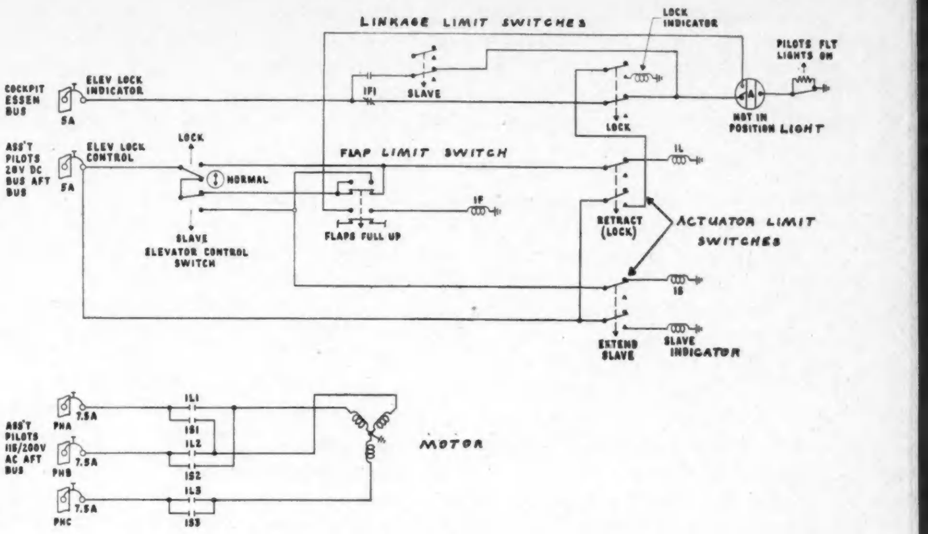


Figure 11
Electrical schematic of elevator actuator system

Since the operation of the elevator lock actuator was considered critical to a safe landing or takeoff, complex mechanical and electrical systems were evolved for maximum reliability. The actuator was specified to incorporate an irreversible acme screw so that in case of an actuator or electric failure during operation the system would hold. An extensive indication system using both the actuator and external switches was developed to inform the pilot exactly at all times as to the status of the elevator mode. The mechanical linkage is such as to provide an over center locking mechanism, thus relieving the actuator of load after it has performed its required function.

A multipole limit switch was installed on the elevator lock linkage mechanism to be used for indication purposes. As previously pointed out, indication of the actual position of the elevator mode was considered so critical that two independent indication methods and circuits were designed. The first was a simple light powered by the 28v dc essential bus and activated by a switch on the mechanical linkage to light when the mechanism is locked mechanically. When the wing flaps are in the fully up position the light is out. The second system is powered along with the other components from the co-pilot's bus and uses a barber pole type of indicator along with independent indication limit switches in the actuator, as well as a mechanical linkage switch as used in the alternate circuit. The design is such that indication in the locked position is obtained from the actuator which is in series with the linkage switch to the indicator. If for any reason a malfunction should exist in the actuator or its switch mechanism, a lock indication could not be obtained unless the linkage switch was operated. Therefore, false indications are only very remotely possible.

Another precaution taken with the elevator lock system was the use of independent position limit switches working in conjunction with the power relays to guard against inadvertent operation in the event of a plus fault on the indication system. However, care must be taken to insure proper synchronization of the position and indication limit switches with this system.

The location of the elevator lock actuator in the stabilizer posed many wiring problems, not only from an operational standpoint, but also to allow for future servicing and engineering changes. Due to the long wire run, the inrush of the alternating current motor was held to a maximum of 300% and the minimum allowable wire size was used. If the inrush were allowed to approach 400%, the additional wire weight would have exceeded the weight of the actuator. The speed of operation for a stroke of 4.5 inch is 15 sec at no load and 25 sec at 3,000 lb load with a maximum operating load of 6,000 lb.

The synthetic feel system is of the type wherein the stick force is proportional to stabilizer deflection Δ and airplane dynamic pressure q. While the feel system is similar to that of the rudder system, it differs in that the proportionality with q is obtained by using a variable bell crank that has an arm length proportional to $\sqrt{q}$. Thus operation of the q actuator, in addition to changing the moment arm position, also cranks additional trim into the system. The dynamic pressure is picked up from the pitot-static system by a pressure transducer which transmits a signal proportional to $\sqrt{q}$ to a control box. The feel system used a solid shaft as a torsion spring, the spring deflection proportional to the stabilizer deflection.

As shown by Figure 8, longitudinal control is provided by duplicate systems, each furnishing one-half the control force. Each of the dual control column cables is connected through a relief spring, so that in the event of a q actuator failure the system can thus still be operated. The two longitudinal feel systems receive indexing information from different independent sources, one from the pilot's pitot-static system and the other from the co-pilot's pitot-static system. Each q actuator

is operated independently. However, a comparison feedback circuit is incorporated which compares the stroke of each actuator and lights a warning light when the out-of-band tolerance is exceeded. The warning light is located on the engine instrument subpanel alongside the q stop warning light. Figure 5 is a schematic of the q actuator. The actuator is similar to the q stop actuator rated at 200 lb at 0.21 in/sec and 400 lb at 0.11 in/sec with a stroke length of 7.9 inch.

The control forces are trimmed by adjusting the solid shaft torsion spring previously mentioned by means of an electric actuator, in a manner similar to that discussed under directional control. Maximum reliability was required from the permanent magnet 28v dc motor actuator from both a mechanical and electrical standpoint. Two identical irreversible acme screw actuators were connected in parallel mechanically of sufficient rating that in the case of mechanical screw or actuator breakage the other unit could assume the load. The specification of acme screws automatically solved the inadvertent electrical runaway problem in case of plus faults to one actuator. Either the circuit breakers would immediately clear the fault or electrical burnout would occur, since the actuator would be in a locked rotor condition continuously. The stabilizer trim actuator has a speed rating of ± 20% at 200 lb and ± 10% at no-load.

HYDROFLAPS/SPEED BRAKE

The hydroflaps are operated in two modes from the hydraulic utility system. In the air they serve as speed brakes wherein two positions are supplied; that is full out or in. However, since attempting a landing with the hydroflaps out would be disastrous to the flaps, this possibility is ruled out by an interlocking arrangement with the wing flap switch and engine throttle levers along with a dive brake lockout relay.

After touchdown the hydroflaps must be used individually or in unison to varying degrees, depending on the maneuver being attempted. A variable resistor, not shown on the directional control schematic, is applied to each toe pedal. A permanent magnet 28v dc actuator is used to operate the hydraulic valve connected with the right and left hand hydroflap actuator cylinder. A follow-up potentiometer is made a part of each actuator and the deflection signal produced is coupled with the hydroflap position resistor to a bridge circuit and a micropositioner relay. The two 28v dc hydroflap indicators on the pilot's subpanel indicate the position of the hydroflaps. In case of actuator or electrical failure, the hydroflaps can be operated by manually controlling a release lever in the auxiliary power unit compartment.

While the scope of this paper is limited to the role of electro-mechanical systems associated with the flight control system, the SeaMaster airplane has other interesting and complicated actuator systems. A number of actuators of different types, speeds and ratings are combined and programmed in a system to perform automatically a complete function such as the spray strip actuator system, the alternate air door system, and the nacelle bypass door system.

ACKNOWLEDGMENT

It would be difficult to identify all the Martin people who have contributed to this paper. The engineers and other personnel who contributed to Engineering Reports ER 5909, ER 5997, ER 9559, Electrical Wiring Diagrams, as well as The Pilot's Utility Handbook, should receive special recognition, as it was from these sources that the material presented herein was derived.

THE USE OF MODELS IN AEROELASTIC ANALYSIS†

by J. A. McKillop*

Avro Aircraft Limited

SUMMARY

The influence of aeroelasticity on modern aircraft design is outlined together with the requirement for aeroelastic data which cannot be obtained from analysis. The development of experimental methods to supplement analytical work is reviewed and some examples presented. The theory of aeroelastic model design is briefly treated and the types of models required for different applications are discussed. Model construction, instrumentation and test techniques are presented and some conclusions are derived regarding the role played by aeroelastic models in the design process.

INTRODUCTION

In the field of aeronautical engineering it is often the case that the ability to provide high performance exceeds the ability to understand the effects of such high performance. This is particularly true of the science, or perhaps one should say art, of aeroelasticity.

Aeroelastic problems have always influenced aircraft design. Often, however, the interpretation of this influence has been so poor that completely misleading conclusions have been drawn. Beginning with the destruction of the Langley "Aerodrome" in 1903, for example, there were many structural failures of wire-braced monoplane wings. It is now clear that the cause of these failures was divergence, brought about by the extremely low torsional stiffness provided by the wire bracing. Unfortunately, at that time, the opinion was formed that the monoplane was an inherently bad design. For the next 15 or 20 years – until the analytical treatment of divergence was formulated – few military monoplanes were built.

The phenomenon known as flutter first became a problem during World War I and has appeared in many forms since. But the theoretical treatment of its mechanism, even in the simplest form, did not follow until 1928. Even now, methods of flutter analysis, complex as they have become, cannot always provide an adequate description of the problem. In addition, the need for accurate prediction of aeroelastic phenomena is becoming more and more pressing. The designer therefore is forced to employ experimental methods in many cases to solve aeroelastic problems.

This paper, then, is a brief review of the role played by elastic models as supplements to analysis in the design process of a modern airplane.

†Paper read at the Joint I.A.S./C.A.I. Meeting in Ottawa on the 7th October, 1958.

*Chief of Aeroelasticity.

THE IMPORTANCE OF AEROELASTICITY

> "An increase in the flying speeds of aeroplanes has introduced problems of design distinct from those of strength. The aircraft structure is necessarily flexible and relative movement of its component units takes place under aerodynamic loading. If such movements are excessive, flutter and other dangerous phenomena are liable to occur at speeds within or only a little beyond normal speed range."

These words were written 25 years ago regarding an aircraft with a speed of 150 miles an hour. They have even more meaning today. Examination of a structural design process clearly shows the application.

The principal objective of a structural design is, of course, the provision of adequate strength. In the case of an airplane wing, the loads that the structure must sustain are usually based on the gross weight and the design load factor of the aircraft and are independent of speed. As designs are refined, the applicable load factors may be made lower, in order to permit increased performance by decreasing weight.

A structure designed on the basis of strength alone has a certain inherent stiffness level, which will define the aircraft's reversal, divergence and flutter speeds to a first approximation. This aeroelastic boundary has therefore been defined by a process which does not involve consideration of the aircraft's performance capability.

Until recently this approach was satisfactory, since with normal construction techniques the stiffness level was adequate to prevent aeroelastic difficulties from having a major design influence. However, the vast increase in performance potential of recent years has drastically altered the situation. The designer now faces the additional requirement for adequate stiffness as well as strength, which he must provide in a structure of minimum weight. The penalty for the lack of either is a structural failure. The penalty for an excess of either will be a serious weight penalty. It is obvious, then, that the accurate definition of aeroelastic effects is necessary for the design of an efficient structure.

Several recent developments have introduced great difficulties in the theoretical treatment of these problems. In the search for higher performance, wings of many unusual shapes have appeared (Figure 1). These planforms have been selected to provide improved aerodynamic performance from the drag or stability point of view, but they present serious problems for the aero-

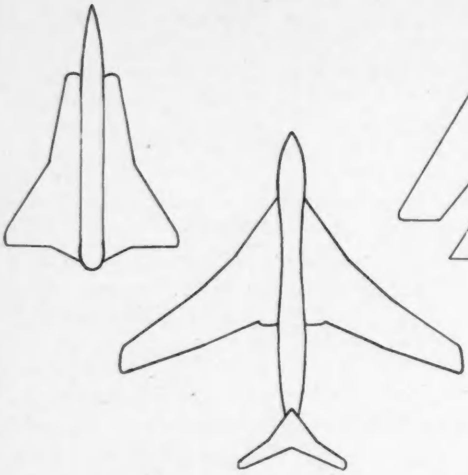


Figure 1
High performance wing planforms

elastician. The prediction of air load distribution, particularly for the oscillating load, is an extremely complex problem which must be solved if aeroelastic effects are to be analyzed. Unfortunately, adequate theoretical techniques have not been developed to cope with the difficulties involving low aspect ratios and high or compound sweep.

Wings of high performance airplanes are always thin. Consequently, as the aircraft proceeds through the development phases, requirements for carriage of extras are usually met by external stores. Additional fuel tanks, bombs, rockets, missiles and even engines may appear on the wing. Air loads on these stores are almost impossible to calculate. As an extra complication, operation at transonic Mach numbers creates interference effects and complex shock patterns which are completely impossible to forecast.

These are merely a few of the more important examples of the increased difficulties faced by the theoretical aeroelastician. He has therefore been forced to seek solutions by experimental means. It is too late in the design procedure to investigate aeroelastic effects by flight test, although this is of course necessary as the final step. Because of these problems, the aeroelastic model has been developed for use as a design tool.

CONCEPT OF AEROELASTIC MODEL TESTING

The framework of aeroelastic test procedures is subject to wide variations. Some models are designed and tested to confirm or deny theoretical work whose validity is in doubt. Others are used as research tools for the provision of empirical data for later use in design. Still others are used as analogs of particular designs, to provide quantitative information on suitability for a requirement or behaviour patterns.

Testing techniques vary widely. Models are tested in wind tunnels, attached to high speed rockets, mounted on free falling bombs, carried on rocket sleds, and exposed to shock tube blasts. The aeroelastician must choose the one which is best for his purpose in view of the facilities available to him. Above all, he must keep his objective firmly in mind. Too often, in analyzing a dynamic stability test, it seems as if the equations of motion are being investigated. This is not the case; it is the coefficients which are investigated and interpretations of test data must be directed with this intention.

HISTORICAL BACKGROUND

One of the earliest and most comprehensive aeroelastic model programs in the literature was that carried out on the DH Puss Moth in 1932[1]. Nine accidents involving failure of the wings of this aircraft occurred over a period of about two years. The explanation of these failures could not be found through examination of the strength characteristics of the aircraft and since several pilots had reported oscillations in flight some type of flutter was suspected.

As the mechanism of flutter and its theoretical treatment had not been adequately formulated at that time, elaborate elastic model tests were carried out to investigate the cause of the oscillations. The model (Figure 2) was one-quarter scale with a rigid centre section and flexible wings and rear fuselage. Several potential flutter conditions were brought to light during these tests, both on the wings and the empennage.

Cause of the accidents was established as a flutter case involving wing bending, aileron rotation and fore and aft oscillation of the wing allowed by the single bracing attachment. The aileron mass balance was shown to be ineffective for this motion, permitting a sudden violent flutter. Modifications to the mass balance arm and to the strut attachment provided a cure, but it is difficult to see how this could have been effected without the model program.

Another more recent flutter model program, which must have been quite elaborate, was that carried out on the HE 219. This work is shown in a German film produced by AVA. The model was quite large, apparently about one-quarter scale (Figure 3). Tunnel suspension was quite elaborate since no attempt was made to actually fly the model in the tunnel. The model had provision for alteration of control surface and tab mass and stiffness parameters. A quick-acting brake was able to clamp the model to prevent its destruction.

Figure 2
DH Puss Moth flutter model — model viewed from door of wind tunnel

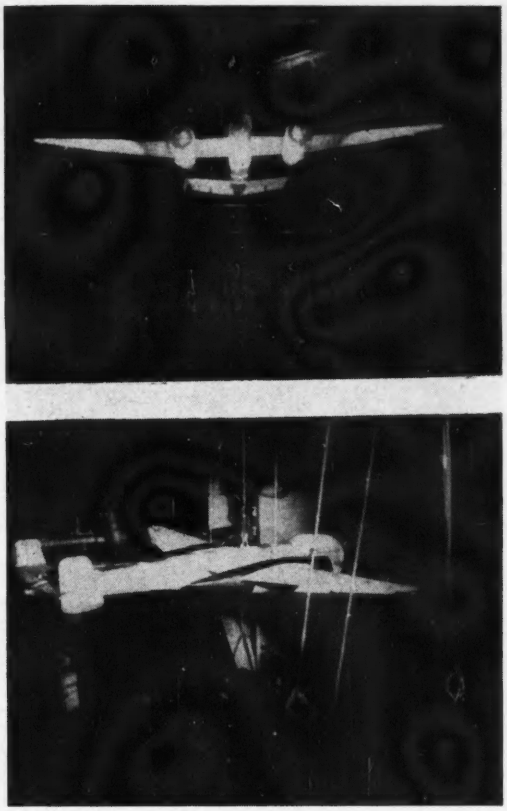
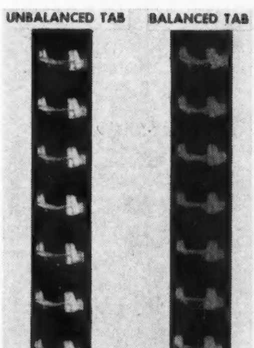


Figure 3
HE 219 flutter model



Mild rotation of elevator and tab

Violent bending of fuselage and tail

Figure 4
Elevator-tab flutter

The model had an amazing number of modes of flutter. Also shown was a shift from symmetric to anti-symmetric wing flutter as speed was raised, followed by examination of several types of control surface and tab flutter.

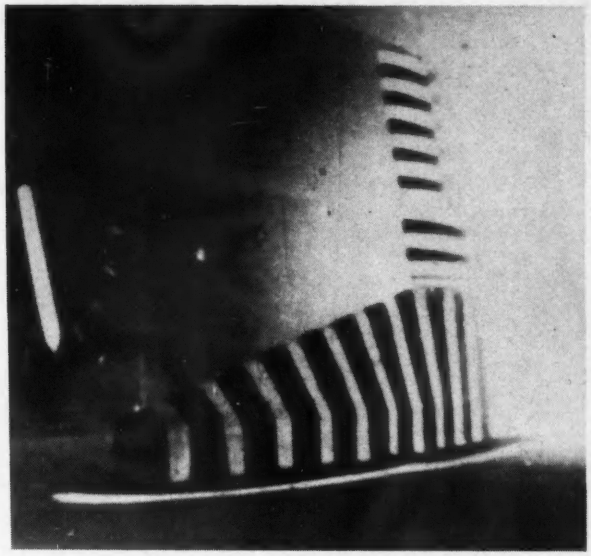


Figure 5
Simple flutter model

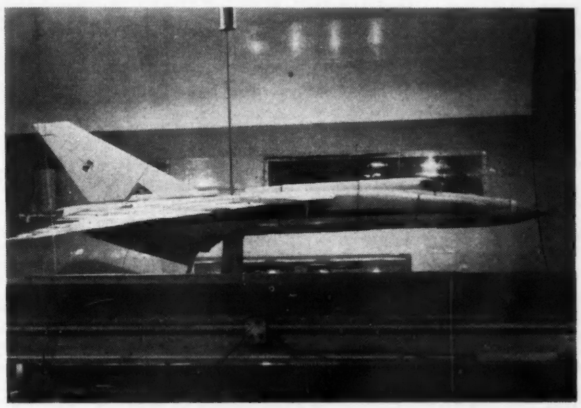


Figure 6
Free flying flutter model

A point of interest of this series of tests is the extremely violent flutter mode of the mass balanced elevator tab compared with the unbalanced configuration as shown in Figure 4. This illustrates very clearly the folly of arbitrary tab mass balance.

These two test programs are illustrations of analog type models used to investigate problems of specific designs. Some such program is almost always carried out for a modern high performance airplane. Models may be relatively simple, allowing only a few degrees of freedom (Figure 5), and they have the limited objectives of establishing principal types of flutter. On the other hand, a model may be quite complex, designed for a wider investigation, or to provide flutter clearance for a design (Figure 6). Indeed, some designers base the complete flutter clearance program on models with only rudimentary analyses.

Models have been used as well for establishing empirical boundaries. Such a model was designed and built

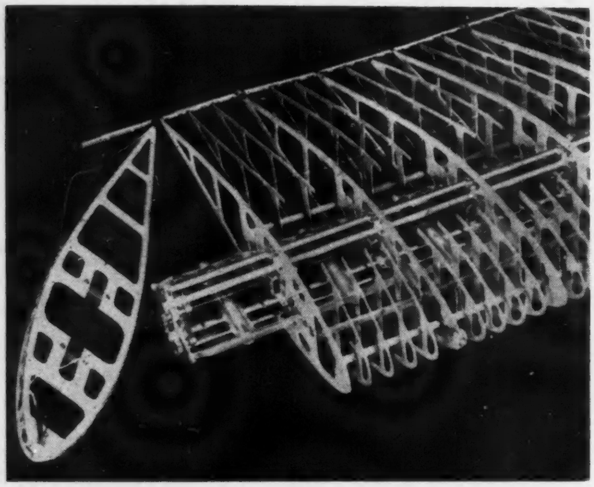


Figure 7
NRC variable stiffness model — interior construction

at NRC[2] (Figures 7 and 8) to investigate the effect of variations in bending and torsional stiffness on flutter speed. These stiffnesses were provided by systems of linkages and leaf springs. Adjustment of these springs allowed the variation of stiffness over a wide range. Contour of the model was made up of plywood ribs with a rubberized fabric cover. Valuable insight can be gained into the mechanism of flutter with this type of model.

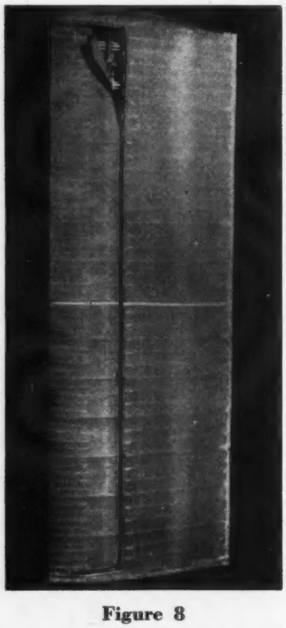


Figure 8
NRC variable stiffness model

In transonic and low supersonic flows, oscillating aerodynamic theories are not well developed. Thus, for some years, several research establishments have been testing models in families to obtain trends of flutter speeds (Figure 9). The models used are usually very cheap and serve to pinpoint critical areas for more exacting analysis when a specific design evolves.

AEROELASTIC MODEL THEORY

The theory of aeroelastic model design is very well covered in the literature[3] and need only be briefly discussed here. The simplest type of model is one designed to simulate only vibration characteristics. However, unless it is an exact replica of the structure it does not offer any advantage over a careful calculation.

Another simple type of model is one designed for steady state aeroelastic tests, which require simulation of stiffness and external shape only. The simultaneous solution of these two problems is not usually difficult. The flutter model, however, requires the simulation of

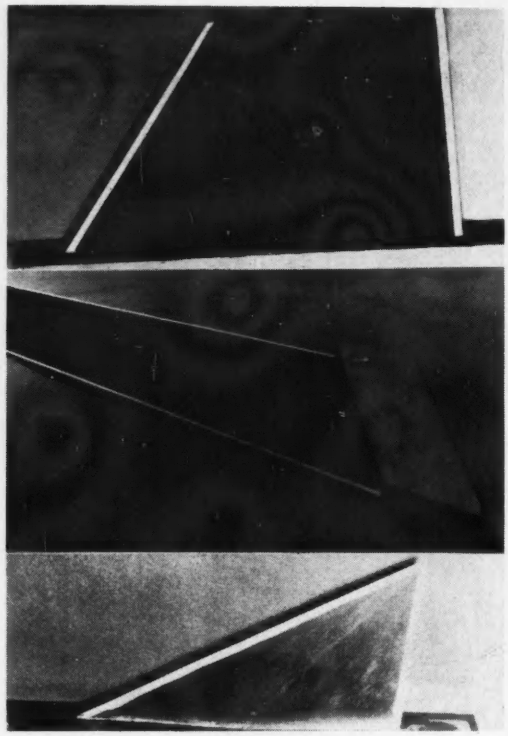


Figure 9
Simple supersonic models

mass, stiffness and external shape, and is the most difficult to design.

The theory of flutter model design is based on dimensionless quantities. If the equations of motion of an oscillating wing in incompressible flow are written in dimensionless form, 10 parameters result which require simulation by the model. The designer then must establish the scaling of the three independent variables – length, mass and time. This problem is not usually difficult for a model in which compressibility effects are not simulated.

Length ratio is fixed by the available tunnel size. Velocity ratio is settled by the operating speed range of the tunnel in relation to the speed range of the aircraft. When this is combined with the length scale, the appropriate time ratio is defined. Mass ratio is found by evaluating the density parameter $\frac{M}{\pi \rho b^2}$. The operating tunnel density compared with the desired flight density, together with the established length ratio, fixes the model mass ratio. In practice, the length and velocity scales are often very close, resulting in a time scale near unity. This is a considerable help in testing as it allows flutter to be controlled and insight to be gained into its mechanism.

Since the strong interference effects and shock wave patterns (discussed in the introduction) are most pronounced at transonic speeds, models must be designed to provide experimental data at representative Mach numbers. Examination of the dimensionless equations for compressible flow shows that the number of required parameters has now risen to 13. The essential dimension-

less parameter is, of course, Mach number. This quantity fixes the model velocity scale within close limits. The length scale is also established quickly by the available tunnel size or rocket or sled capacity. Available tunnel or test altitude density is very often a major stumbling block.

Design of wind tunnels is usually such that a specific velocity and density is provided for a given Mach number. The density is very often quite low, thus making construction of a model to simulate a sea level density parameter very difficult. The model designer may find that the combination of mass ratio and stiffness ratio necessary for his model requires the use of a material with a negative mass or with E four times as great as that of steel.

MODEL CONSTRUCTION

Techniques of model construction vary widely with the type of model desired and the testing medium. The flutter model, since it requires simulation of stiffness, mass and external shape, is the most difficult to design and the techniques may be applied to the simpler vibration or steady state aeroelastic models.

An intriguing approach would be to design a model in which all components are reduced in size uniformly. The theory shows that such a model would have the same flutter speed as the airplane. For high performance airplanes, therefore, tests would be required at high speeds and most high speed wind tunnels are rather small. Sizes of components, then, may become minute.

Consider an airplane of 50 ft span with a wing skin gauge of 0.125 in at a representative section. This would have to be scaled by a factor of from 30 to 50 to fit into a tunnel offering an adequate test density and Mach number. The model span might become about 18 inches and the model skin thickness about three-thousandths. To provide a proper representation of the airplane, the structure must be fabricated from this gauge in exactly the same manner as in the full scale article. This is hardly a practical proposition although this skin thickness can be fabricated using other specialized techniques which will be discussed later.

Low speed models can usually be fairly large, as the available tunnel size is greater and the designer thus has considerable latitude in his design. For wings whose structure has reasonable aspect ratio, the single mass spar to provide bending and torsional stiffness is adequate. Several ingenious designs exist for spars which must have high ratios between bending and torsional stiffness or where chordwise bending stiffness is also important. The contour must then be filled out and the proper mass distribution provided. A balsa shell is often used for the contour as it is very light and allows greater scope for adjusting the mass (Figure 10). If the mass ratio of the model is such that plenty of weight is available for the shell structure, a much more rugged construction can be made of fibreglas with a foam core. However, balsa covered models are amazingly rugged and, if damaged, are easily repaired.

For the simulation of the structure of a low aspect ratio wing, such as a delta, something more elaborate than a single spar is required. Here, the stiffness analysis of the aircraft itself should play an important part in the approach to the model design. In order to reduce the number of the simulation uncertainties to a minimum, the model should be designed on the basis of the structural analysis. If the wing is analyzed as a network of beams, the model should also be designed in this manner (Figure 11).

On the other hand, if the wing is analyzed by one of the methods which treats it as a plate, a corresponding plate should be used to provide the model stiffness.

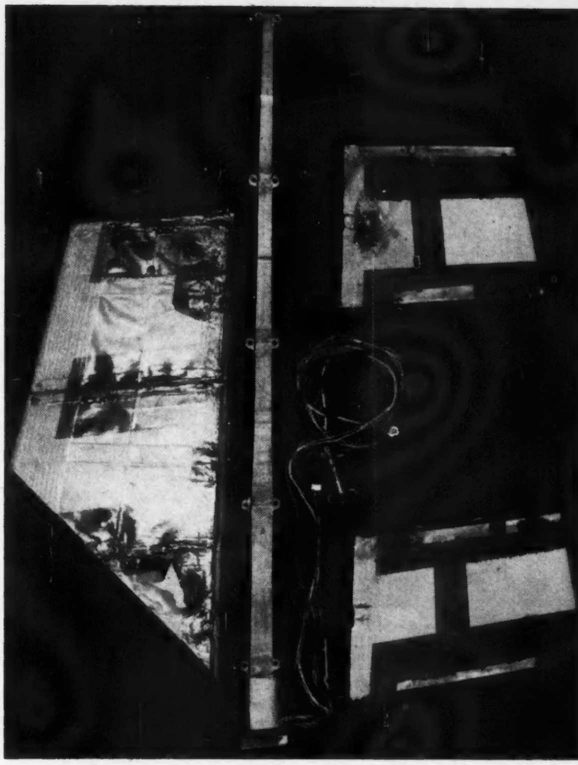


Figure 10
Single spar flutter model

Figure 11
Multispar flutter model

Very interesting techniques have been developed for this purpose, involving plates with patterns of holes or elaborate contouring. The section may then be filled out with a light segmented covering (Figure 12). The designer should also attempt to keep his design as flexible as possible (in the broad sense) with a view to making changes as more concrete stiffness information about the airplane becomes available.

High-speed models require a velocity ratio of unity and since the length ratio may be large due to tunnel size limitations, the frequency ratio also becomes high. The stiffness required for this ratio forces the designer to employ very efficient structures. The efficient technique developed at Cornell[4] is an indication of what is required when the test section density is low. However, this is an extreme. The three-thousandth skin mentioned earlier may well be required, but balsa cores may be used for stabilizing such skins providing the balsa is carefully selected for uniformity. Complicated surface bonding technique may also be eliminated. A simpler approach of punching holes in the skin through which glue is pressed may be used. The efficiency of this construction is excellent, since it is common for a tension skin to fail under test before the compression skin buckles. Examples of models with this type of construction are shown in Figures 13 and 14.

Transonic tunnels, providing high test section densities, have been built recently for flutter testing exclusively. These simplify the designer's problems as he no longer must design the structure of the model to such a high degree of efficiency.

Models for the investigation of trends, rather than the simulation of actual airplanes, need not be particularly efficient, and often use single spar construction with solid balsa contours (Figure 15). As it is common to lose a high speed model at a flutter point, these models must be relatively inexpensive or this type of testing would be limited to airframe contractors. These models may have control surfaces to investigate both flutter and the relatively new phenomenon of control surface "buzz" (Figure 16).

INSTRUMENTATION

Experimental work is only as good as the data it provides and considerable effort should be expended on data recording in aeroelastic tests. Of course, a flutter speed may be considered a check point, but some knowledge of how and why a model went down the tunnel, or came off the rocket, is desirable.

Steady state aeroelastic tests may utilize the normal wind tunnel balance system. The model must be designed to be compatible with this system but this is not usually too difficult. A strain gauge at a critical point in the structure may be monitored to ensure that the model is not lost through overstrain.

Rigid models, which are made to oscillate in tunnels to measure derivatives, require load or pressure measurements. Strain gauges are adequate for loads while some ingenious pressure pickups have been developed to measure the pressures on small models[5]. These are crystal type and may be made very small and sensitive. They are not without drawbacks, which will be discussed later.

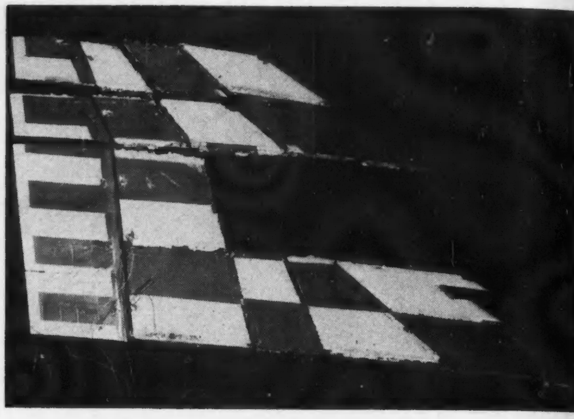


Figure 12
Multispar model covering

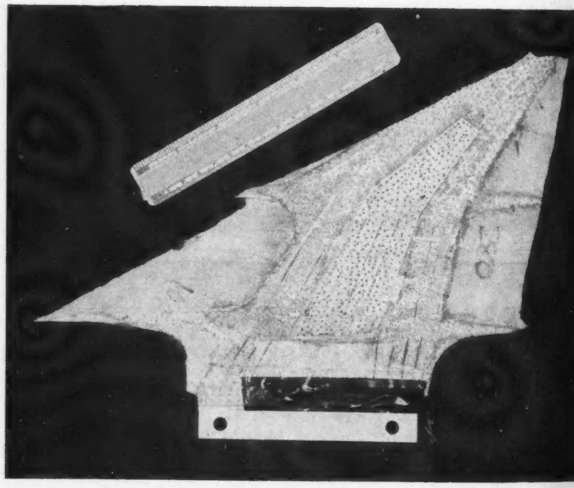


Figure 13
High speed box structure model — cantilever

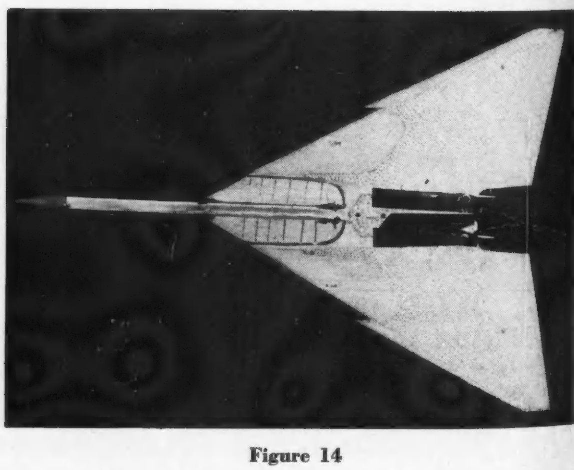


Figure 14
High speed box structure model — full span

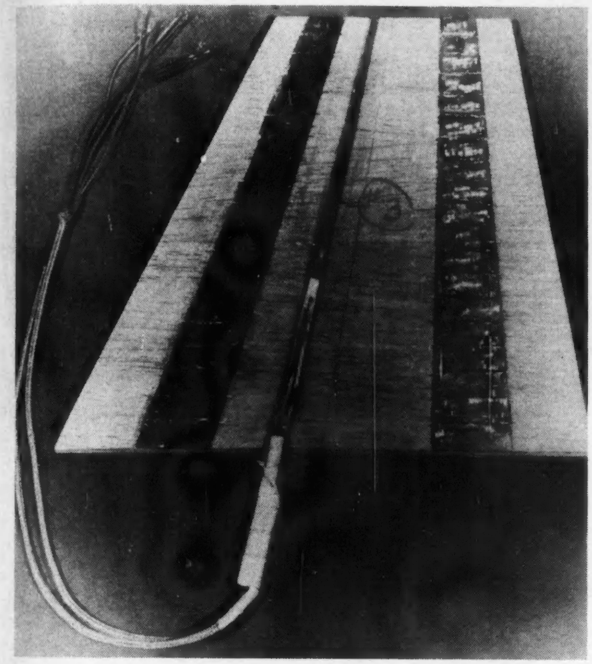


Figure 15
High speed single spar model

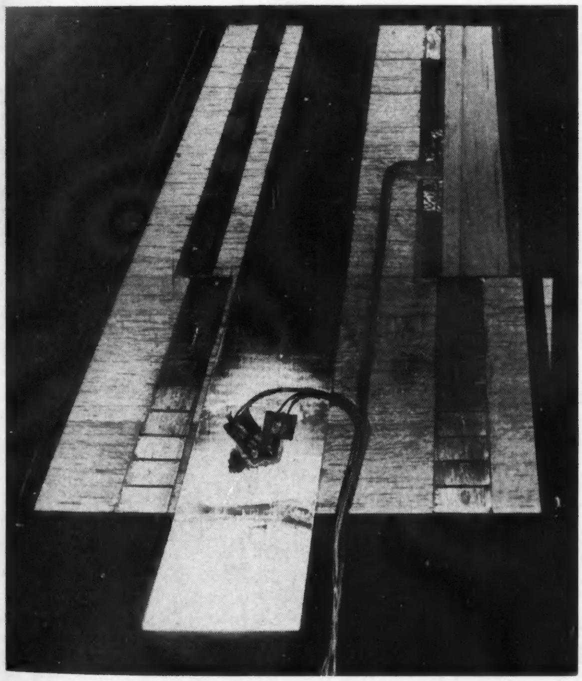


Figure 16
High speed single spar model with control

Flutter tests require the most elaborate instrumentation if satisfactory data are to be obtained. The nature of the phenomenon imposes great difficulties. Flutter is unpredictable, almost instantaneous and usually disastrous. Recording of some kind must be continuous, therefore, with the more elaborate coverage used on the approach to critical speeds. Records should provide the test speed, flutter frequency and the mode shape.

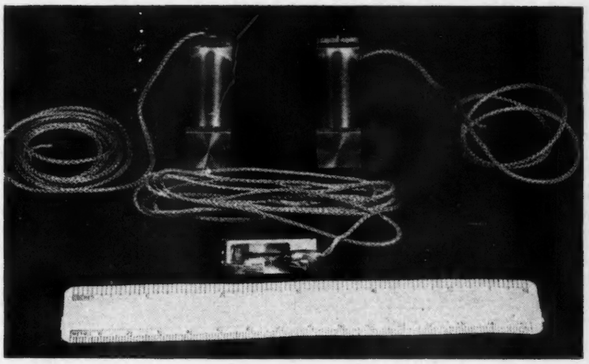


Figure 17
Crystal accelerometers

The strain gauge is once again a very useful tool for this purpose. It can be used to provide frequency and phase indication or, if an elaborate application is made, it can yield the mode shape from an analysis of strain energy. However, if a complicated beam network is being treated, the number of strain gauges is large and their calibration can become exhaustive. Nevertheless, they are reliable, light, easy to apply, rugged and require only a simple wiring setup.

To provide a direct reading of oscillation amplitude, accelerometers may be used. Because of space and weight limitations, the only suitable accelerometers are the crystal type (Figure 17). These can be made very small and are very sensitive, but they have several drawbacks.

The high impedance of the crystal makes the wiring susceptible to pickup from stray fields. Static electricity may also present problems unless care is taken to use teflon insulation for the wiring. To keep lead lengths short, a proper cathode follower amplifier must often be located in the model. If the model design caters for large disposable loads, this is not a problem if subminiature tubes are used. One should resist the temptation to "transistorize" with this type of pickup. Crystal pickups must also be calibrated dynamically.

Their biggest drawback, however, is their high performance as microphones. The noise level in a wind tunnel is high, and elimination of this unwanted response may be very difficult. Nevertheless, because of the great sensitivity of these pickups and ease of interpretation which they offer, they should not be overlooked by the model designer.

In the wind tunnel, another extremely valuable recording tool is available to the experimenter – the high speed motion picture camera. Slow motion movies provide a good indication of the flutter mode and may also show unsuspected peculiarities (Figures 18 and 19). In a high speed test when the model may flutter and disappear in a quarter second or less the camera record is especially valuable.

The difficulty with a camera is its limited film capacity. As flutter is often unpredictable it is not always possible to catch the critical moment unless the camera runs continuously, and this is not practical.

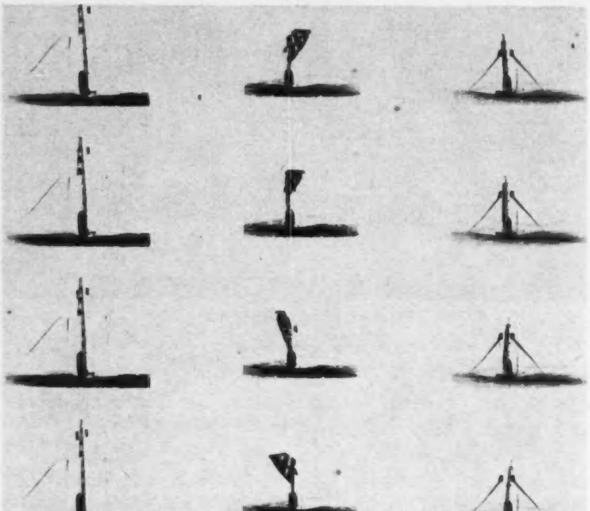


Figure 18
Examples of flutter

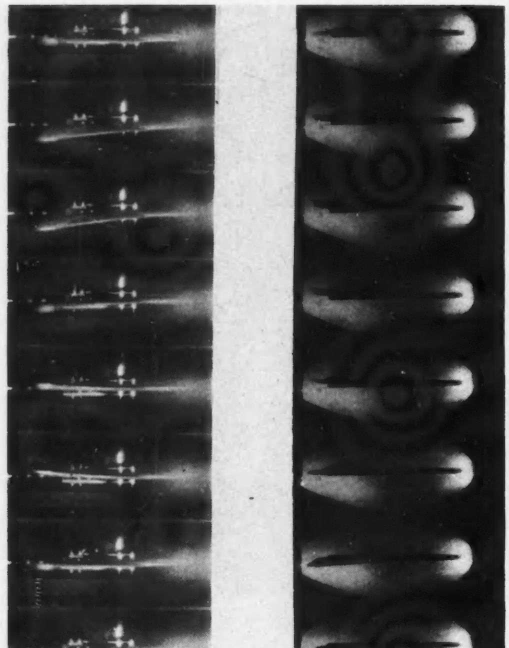


Figure 19
Examples of flutter

Filming rate is sometimes a problem as the high frame rates required of high speed tests often create a demand for light which is difficult to meet. Few tunnels have been designed with proper lighting facilities for high speed photography and many have no provision for photography at all.

Recording instrumentation for rocket, bomb and sled models is similar to that used for wind tunnel models except that the data must be transmitted by telemetry. Cameras are used on sleds and may also be fitted to rockets and bombs if provision is made for recovery.

TESTING TECHNIQUES

Procedures used in model testing vary widely, of course, with the test objective. Measurement of stiffness is, however, common to all.

Low speed models are comparatively flexible, so the method of measuring deflection must not introduce other than constant loads into the structure. For single spar models this is easily done by measuring slope or twist by a reflecting optical arrangement. This procedure gives good accuracy and fulfills the requirement for a passive measurement.

Multispar structures require a large number of measurements and their interpretation becomes difficult. Fortunately, other methods are available. The deflections may be read through a level from scales suspended from the structure, or an elaborate servo depth gauge system may be used[4].

High speed models are more difficult to test as their stiffness is high for their size. An electrical method employing a magnetic core which is attached to the wing is useful in this case. The change in a signal as this core moves in a coil while the wing is loaded gives a good measurement of deflection.

Steady state aeroelastic testing is very similar to normal wind tunnel testing. The essential parameter in such tests is dynamic pressure. The range of incidence available for testing will decrease for strength reasons as dynamic pressure increases and the test procedure should take account of this. It is unlikely that the standard of surface finish of an elastic model will be good enough for direct evaluation of the stability derivatives. However, unless the surface contour is very bad the derivative change as a function of dynamic pressure should be valid.

One valuable use for such tests which is often overlooked is the prediction of stability derivatives for a free flying wind tunnel flutter model. The effects of wall interference and support mechanisms can have a marked effect on stability and require some advance investigation if disaster is to be avoided.

Flutter models must be subjected to much the same program of tests as the complete airplane although some of the problems are different. Stiffness measurement problems have been discussed above. Vibration testing introduces some similar difficulties. Once again the testing device must not affect the properties of either mass or stiffness. It is possible to build an electromagnetic

shaker with a very light coil and no inherent stiffness. Since it is not self-centering, it must be carefully aligned when attached to the model. For very light models, even this small addition may be too much.

Then the experimenter must turn to an air coupled shaker. In its simplest form this consists of a loudspeaker horn placed close to an anticipated anti-node. A more complicated system is provided by pulsed air jets which can be phased and thus excite symmetric or antisymmetric modes.

The mass distribution is not always tested. If the stiffness and vibration tests agree with predictions, the experimenter may have confidence that the mass of segments may be checked and the distribution estimated. With small high speed models, it is customary to cut a representative model into segments for weighing. Then quality control is depended upon to give uniform specimens.

Dynamic wind tunnel tests may be designed to measure coefficients or to evaluate flutter characteristics. Rigid models, which are oscillated in the air stream to evaluate coefficients, require very accurate load and pressure measurements. The difficulty in the test technique is the large load arising from inertia as the test frequency range rises. Very careful test arrangement and measurement are required to minimize this problem[5, 6].

Flutter tests are the most difficult of all aeroelastic tests. A special case, which is an exception, is the research flutter test covering a family of models which is designed merely to evaluate the change of flutter speed with some parameter. Flutter tests of models of particular airplanes, however, are much more involved.

The testing of components, such as wings or empennages, is recommended as a first step in a flutter program. With some types of aircraft this may be adequate. If either body vibration modes or rigid body motions are not expected to influence flutter speeds, cantilever tests can provide all the data required.

Low speed models have time scales which allow some control over flutter. Some kind of brake, stop, or method of rapidly altering a parameter should be used. Care must be taken in the application of such a system, because it is easy to *provide* an instability rather than *prevent* one.

For example, if a flexure-torsion-aileron system is being tested, a clamp which restrains bending but not torsion may aggravate rather than prevent flutter. Considerable effort should be made to measure the subcritical damping of the model. The practice of running up the tunnel until the model breaks is to be deplored. A continuous pen recorder gives immediate reading, allowing a running plot to be kept in order to estimate the proximity of flutter.

As many variations as possible should be tested, such as control stiffness, fuel loading, pod loading and location of external stores. A flutter test which merely yields the flutter speed as the model disappears down the tunnel cannot be considered an unqualified success.

Free flying wind tunnel models are perhaps the most difficult to control. The experimenter is faced with static and dynamic stability problems as well as flutter problems, and steady state aeroelastic effects may play a prominent role in this regard.

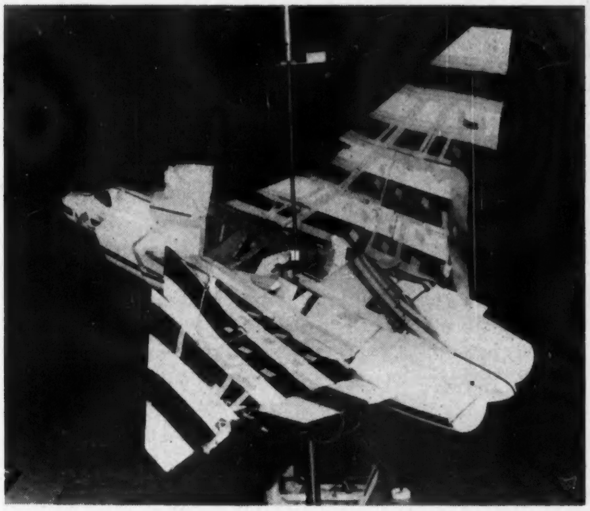


Figure 20
Result of a successful flutter test

Support problems are numerous. A model which flies on the end of a cable must be small to avoid flying into a wall. In addition, dynamic instability in pitch is easily achieved with free flying models which are carried on a rod by a gimbal trolley. Trim and control must be very accurate, as a variation in the flight path of half the mean chord usually means a crash. Provision of control power and instrumentation wiring to the model also becomes a problem, since a large bundle of wires can alter stability characteristics.

A free flying flutter model test should be regarded as a flight flutter test in miniature. Attempts to excite the model in a representative manner with small rocket charges or shakers should be made. These may not be successful, but valuable operating experience is gained even from inconclusive tests.

Success in tunnel tests is very elusive as the turbulence level in a tunnel is high compared with flight and this tends to mask the results of excitation. A free flying model test often ends in a crash, but if flutter is the cause the experimenter has reason to be satisfied with his efforts (Figure 20).

High speed model tests almost invariably result in the loss of the model due to the high frequencies required. Consequently a series of models with varying stiffness or other parameter should be provided to explore the flutter boundary. It may be possible to alter the tunnel stream parameters to provide flutter boundary indication, but many models are still required.

Rocket model tests seem to be the least efficient for provision of information. These tests are one-shot affairs and, due to the dependence on telemetry, the possibility always exists that a minor component failure will nullify the test. However, the ease with which high speed may be obtained as well as the larger model size makes this technique attractive.

Sled tests are a compromise between wind tunnel and rocket tests. The speed program of the sled may be controlled and the test article is recoverable at the end of a run if flutter does not occur. The size of test items

that may be carried on sleds makes them valuable for testing full scale articles. The possibility of building full scale test items with reduced stiffness is intriguing from the experimenter's point of view, although would probably be ruled out for reasons of expense.

The experimenter should keep one thing uppermost in his mind — that a flutter test cannot be regarded as conclusive unless it produces flutter. However satisfactory it is to show that flutter does not occur in the design speed range or above, some non-representative feature of the model design may be restraining flutter. The exception might apply if very complete and accurate subcritical responses are taken and compared with calculations. Nevertheless, it is much more satisfactory to know exactly where the flutter boundary lies.

CONCLUSION

In this presentation, the role played by models as tools for the modern aeroelastician has been reviewed. The several fields which may be explored only by the use of aeroelastic models have been discussed. Some thought, however, should be given to the future of this field.

Aeroelastic considerations will certainly have a great influence on future high performance designs, even in the project stage. Throughout the entire design process, more and more refined analyses will be required, and no doubt theoretical techniques will be constantly improved to meet this demand.

As indicated, however, design techniques usually advance more rapidly than analytical ability, and new methods are required to explore the unknown area. No designer would seriously consider fixing a modern aircraft's external contours by analysis alone. Some experimental verification is necessary.

Nor should he depend on analysis alone for elimination of aeroelastic problems. Proper elastic model programs should be included in the design process at all stages, just as conventional wind tunnel programs are used to evaluate performance and stability.

If such programs are to be properly carried out, the provision of adequate facilities for aeroelastic model testing becomes a requirement. Conventional wind tunnels often are not suitable for flutter tests for parameter or layout reasons. In addition, tunnel personnel are sometimes wary of flutter testing for fear of tunnel damage. Aeroelastic tests in the future will certainly require kinetic heating simulation and this puts an even greater burden on existing facilities.

Therefore, in the planning of new facilities to meet the needs of future designs, it would be shortsighted indeed to cater for elaborate strength, drag, and stability tests, without providing as well for the needs of the aeroelastician, as his work has now become of first rank importance.

REFERENCES

(1) The Accidents Investigation Subcommittee – *Report on Puss Moth Accidents*, ARC R & M 1699.

(2) Hall, A. H. – *Wing Flutter Experiments with Variation in Stiffness and Distortion Form*, National Research Council Aeronautical Report AR-6.

(3) Bisplinghoff, R. L., Ashley, H., and Halfman, R. L. – *Aeroelasticity*, Addison-Wesley Publishing Co.

(4) Targoff, W. P., and White, R. P. – *Flutter Model Testing at Transonic Speeds*, Paper delivered at 25th Annual Meeting of I.A.S.

(5) Laidlaw, W. R. – *Theoretical and Experimental Pressure Distributions in Oscillating Low Aspect Ratio Wings*, MIT Aeroelastics and Structures Research Laboratory Report 51-2.

(6) Greidanus, J. H., van de Vooren, A. I., and Bergh, H. – *Experimental Determination of the Aerodynamic Coefficients of an Oscillating Wing in Incompressible, Two-dimensional Flow*, National Aeronautical Research Institute Reports F. 101-4.

SOME AERODYNAMIC CHARACTERISTICS OF WING-MOUNTED LIFTING FANS FOR VTOL APPLICATIONS†

by R. L. Wardlaw* and N. V. McEachern*

National Research Council

SUMMARY

Wind tunnel force measurements have been carried out on a wing-fan combination; the high-solidity fan was embedded in a two-dimensional symmetrical wing, with the fan axis normal to the wing chord-plane.

Results are discussed and compared with a simple momentum theory, with a view to their usefulness in VTOL project studies. Over a limited range, fan power and model force measurements provide reasonable correlation with theoretical predictions.

An understanding of the flow in the vicinity of the fan is facilitated by surface pressure measurements and water tunnel flow visualization studies.

A method of applying the results to performance analyses is considered.

INTRODUCTION

In the National Aeronautical Establishment low speed wind tunnel a series of tests has been conducted on a fan embedded in a wing such that the fan axis was normal to the wing chord-plane. These tests have arisen from considerations of VTOL configurations using fans as lifting devices.

The VTOL concept of particular interest here is one that would employ a dual-purpose gas turbine powerplant. This engine, in cruising flight, would be used as a conventional jet thrusting device or, in the hovering and transition phases, as a gas producer, the output driving a lifting fan on an independent shaft by means of a turbine. The transition phase from hovering to conventional forward flight would require that the fan jet could be deflected rearward through a small angle, thereby providing some forward thrust. With increasing aircraft forward speed, a portion of the aircraft weight could be supported by conventional wing lift. Eventually it would be possible to convert the engines, one by one, from fan drive to jet thrusting duties.

Details of powerplant requirements and fan drive methods will not be discussed in detail. However, some analysis of this aspect of the problem has been done at the NAE[1]. The thermal cycles of various combinations of fan-drive techniques (e.g. tip turbine, geared hub turbine) and engine types (e.g. single stream, dual stream) have been analyzed. From thermodynamic and weight considerations the combination of a tip turbine driven fan and a single stream engine shows the most promise, and the power matching between hovering and cruising flight requirements is not unreasonable.

The wind tunnel tests were conducted in consideration of a VTOL configuration of the type described above and were designed to determine the aerodynamic behaviour of wing-mounted fans with particular emphasis on the forward flight or transition phase. The test results are discussed and compared with a simple momentum theory, with a view to their applicability in VTOL project studies. A method of applying the results to performance analyses is considered.

LIST OF SYMBOLS

A	wing aspect ratio
A_a	fan annular area, ft²
A_d	fan disc area, ft²
C_D	drag coefficient = $\dfrac{\text{wing drag with fan hole covered}}{qS}$
C_L	lift coefficient = $\dfrac{\text{wing lift with fan hole covered}}{qS}$
$C_{M_{c/4}}$	pitching moment coefficient = $\dfrac{\text{wing pitching moment with fan hole covered}}{qSc}$
C_{D_0}	effective minimum profile drag coefficient
D	fan tip diameter, ft
ΔD	drag increment due to fan, lb
E	number of engines driving fans
G	dimensionless parameter relating geometry of fan to that of wing
K_p	power coefficient = $550\ \Delta P \sqrt{\dfrac{\rho A_d}{\Delta L^3}}$
ΔL	lift increment due to fan, lb
ΔM	pitching moment increment due to fan at $0.3c$, ft-lb
N	fan rotational speed, revolutions/sec and per cent rated engine rpm
ΔP	fan horsepower
S	wing area, ft²
T	engine thrust, lb/engine
V	free stream velocity, ft/sec
V_f	axial air velocity at fan, ft/sec
V_j	final velocity of fan jet, ft/sec
ΔV	change of velocity from V to V_j, ft/sec
W	aircraft all-up weight, lb

†Based on a paper presented at the Annual General Meeting of the C.A.I. in Toronto on the 27th May, 1958.

*Research Engineer, Division of Mechanical Engineering.

$Z = V\sqrt{\dfrac{\rho A_d}{\Delta L}}$

c wing chord, ft

e Oswald's span efficiency factor

m fan air mass flow, slugs/sec

p_t power loading $= \Delta L/\Delta P$, lb/hp

Δp (local static pressure) – (free stream pressure), lb/ft²

q dynamic pressure, lb/ft²

t wing thickness, ft

w_t hovering fan loading $= \dfrac{\Delta L}{A_d}$, lb/ft²

α angle of attack, degrees

β outlet vane angle relative to wing chord, degrees

μ absolute viscosity of air, lb-sec/ft²

ρ air density, slugs/ft³

θ fan jet angle relative to wing chord, degrees

WIND TUNNEL MODEL

Figure 1 shows the model installed in the NAE low speed wind tunnel. The wing itself was basically two-dimensional as it spanned the full tunnel height. The fan duct had a bell-mouth intake faired to the wing upper surface. Downstream of the rotor blades was a row of anti-rotation blades with their trailing edges flush with the aerofoil lower surface. A set of variable angle outlet vanes was provided in order to deflect the fan jet rearward. These vanes protruded into the airstream and spanned the fan jet.

The fan drive consisted of shafts supported by ball bearings and connected by a pair of mitre gears to a 6 hp motor mounted inside the wing. The motor was a jacketed, water-cooled, three phase induction motor and was powered by the laboratory variable frequency power supply.

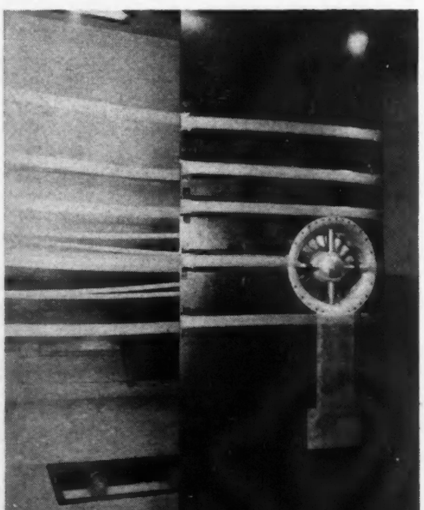


Figure 1
Fan-wing wind tunnel installation with surface pressure tubes

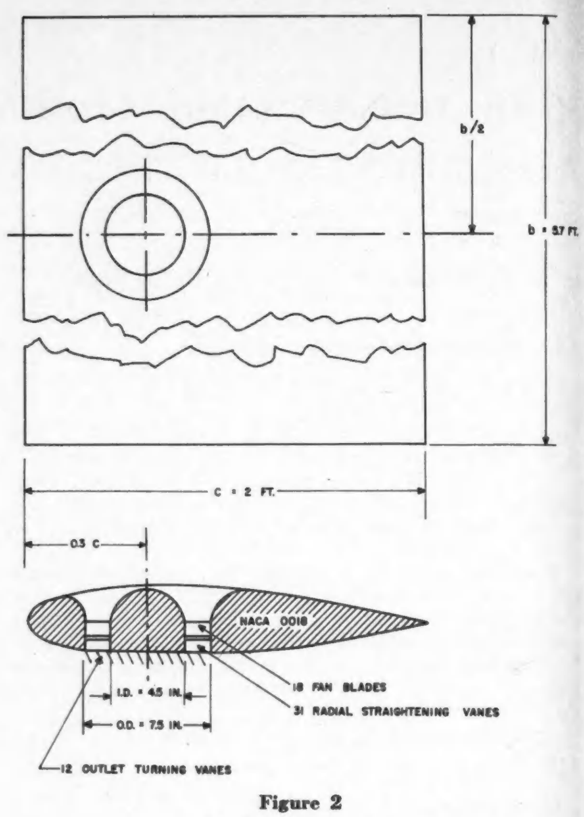


Figure 2
Fan-wing geometry

Dimensions of the wing and fan assembly are detailed below and also are shown in Figure 2.

Wing
Section – NACA 0018
Chord – 2 ft
Span – 5.69 ft

Fan-Assembly
Location – mid span and 30% chord
Hub diameter – 4.5 in
Tip diameter – 7.5 in
Number of rotor blades – 18
Rotor blade chord – 1.05 in
Number of stator blades – 31
Stator blade chord – 0.914 in
Maximum rpm – 15,000
Static disc loading at 15,000 rpm – 60 lb/ft² based on annulus area
Number of outlet turning vanes – 12
Outlet vane chord – ⅜ in
Outlet vane shape – 30° circular arc

FORCE TESTS

The test results are presented in terms of incremental values of lift, drag, and pitching moment, due to the presence of the fan; these values were obtained by subtracting corresponding force values from measurements made with the fan hole smoothed or faired to the normal wing shape (Figures 3 and 4).

It should be noted that no wind tunnel jet boundary interference corrections have been applied to the data,

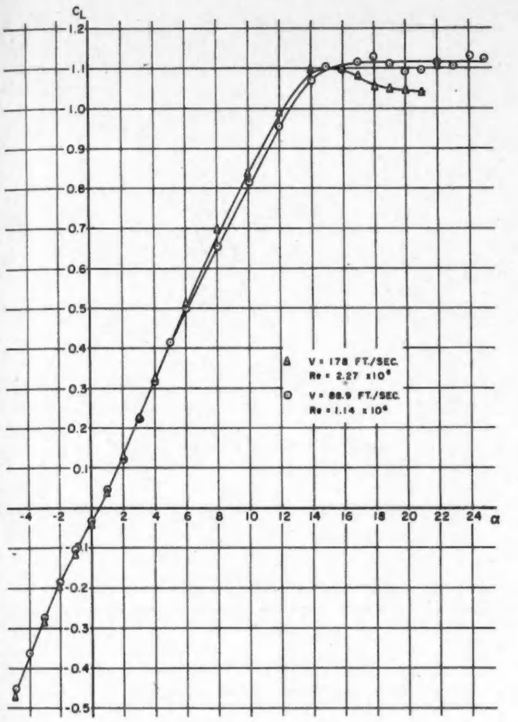


Figure 3
Lift vs angle of attack with fan inlet and outlet covered

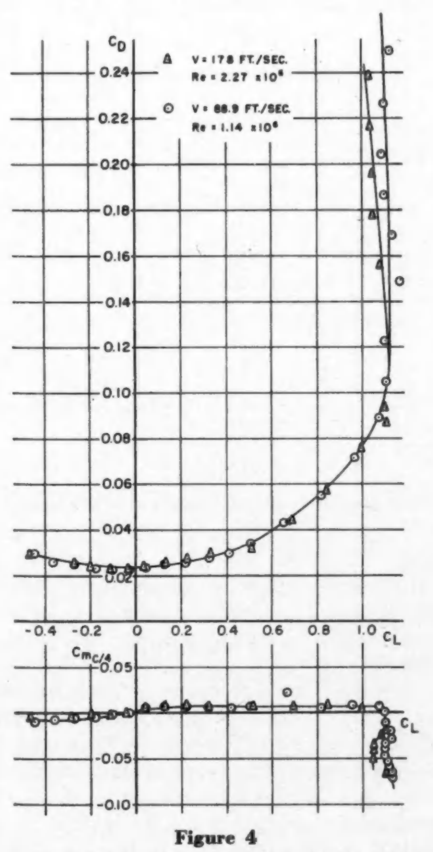


Figure 4
Drag and pitching moment vs lift with fan inlet and outlet covered

since at present no rational method has been developed that is applicable to tests where a jet is directed normal to the main airstream. There are some indications that these corrections are not as large as might be otherwise expected. A wool tuft screen placed one chord behind the wing trailing edge showed (Figure 5) that the jet was bent sharply rearwards even when no outlet vanes were used, which would tend to minimize the constraint effect on the jet. Secondly, for the zero forward speed or hovering case it is believed that the wall effect is small inasmuch as force measurements with the jet blowing out the open wind tunnel access door were only about 5% higher than values with the door closed.

In order that the presentation of results be as general as possible and bearing in mind the possibility of "collapsing" the data with respect to some variables, it is desirable to consider the dimensionless groups or parameters that might be used. Normal dimensionless analysis leads one to the following functional relationship:

$$\left.\begin{array}{c}\dfrac{\Delta L}{\rho N^2 D^4}\\[2mm]\dfrac{\Delta D}{\rho N^2 D^4}\\[2mm]\dfrac{\Delta M}{\rho N^2 D^5}\\[2mm]\dfrac{550\Delta P}{\rho N^3 D^5}\end{array}\right\} = f\left(\frac{V}{ND}, \frac{V}{V_t}, \frac{\rho V_t D}{\mu}, \alpha, \beta, G,\right)$$

These groups can be modified in many ways but the above appears to be the most useful combination for our immediate purpose. One logical change would be to replace ND by V_t. However, our fan mass flow data is incomplete and furthermore it is shown later that this modification would be unwarranted. The symbol G, above, represents the various possible geometrical parameters, such as $\frac{D}{c}$, $\frac{D}{t}$, fan location and, in the case of a multiple fan system, the fan spacing. These factors are of obvious importance, but the model is of fixed geometry and therefore no geometrical parameters can be considered.

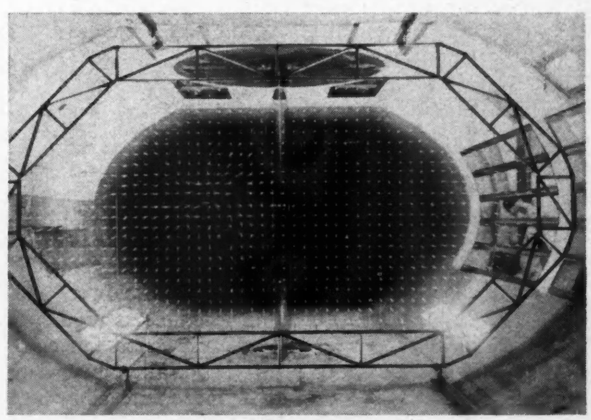


Figure 5
Wool tuft screen behind model
$\alpha = 0°$ $\qquad \frac{V}{ND} = 0.46$

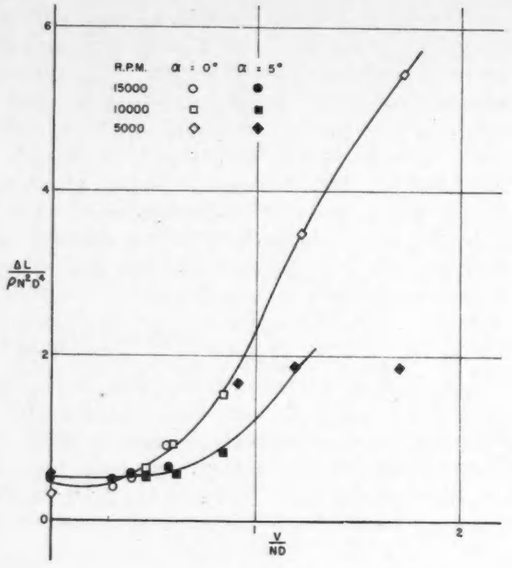


Figure 6
Lift vs advance ratio, no outlet vanes

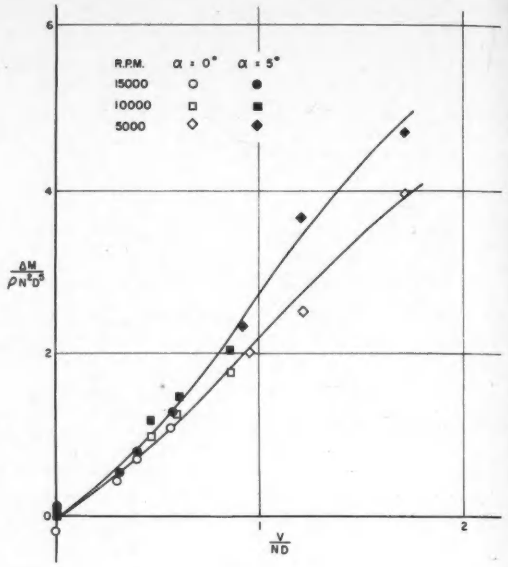


Figure 8
Pitching moment vs advance ratio, no outlet vanes

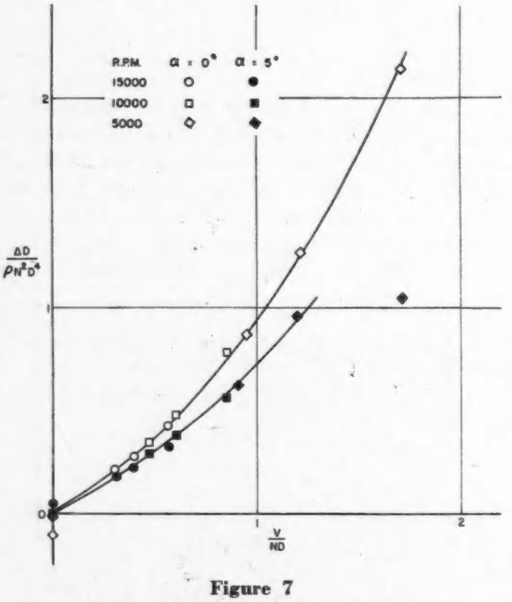


Figure 7
Drag vs advance ratio, no outlet vanes

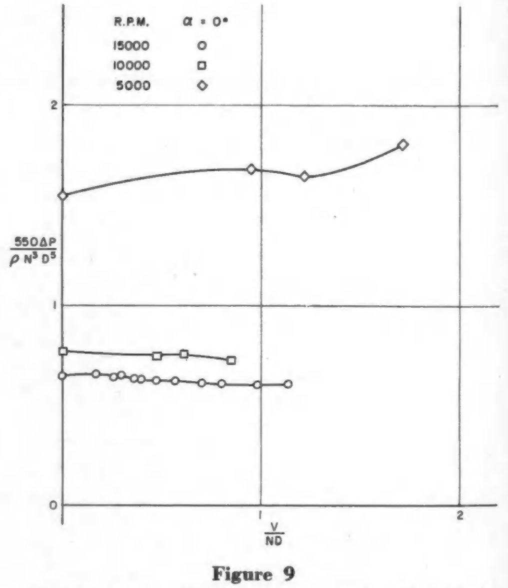


Figure 9
Shaft power vs advance ratio, no outlet vanes

Figures 6, 7, 8 and 9 show the experimental values of lift, drag, pitching moment and power increments obtained without outlet vanes, over a large range of advance ratio V/ND. With the exception of power data, these figures demonstrate that the coefficients used successfully "collapse" the data with respect to fan rotational speed. It is thought that the reason the power data do not collapse is due in part to inaccurate allowance for motor losses when operating at small fractions of full-load power. The large increases of lift and drag were not predicted by simple momentum considerations and consequently some water tunnel flow visualization studies and surface pressure measurements were made in order to provide some understanding of the flow pattern near the fan. These studies will be discussed later in the text.

It is interesting to replot the pitching moment data in terms of the position of the centre of pressure of the fan lift (Figure 10). The centre of pressure is found to have a maximum shift at low advance ratios where it moves well ahead of the wing leading edge.

In preliminary project study analyses it was found that only the lower advance ratio data ($V/ND < 0.7$) were required, particularly with high fan disc loadings

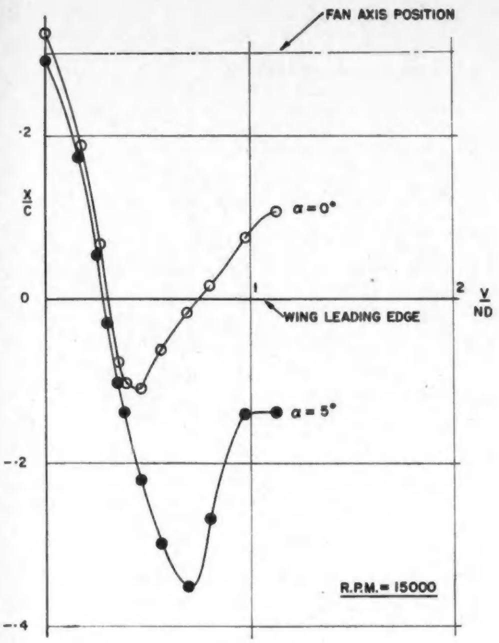


Figure 10
Centre of pressure of fan lift, no outlet vanes

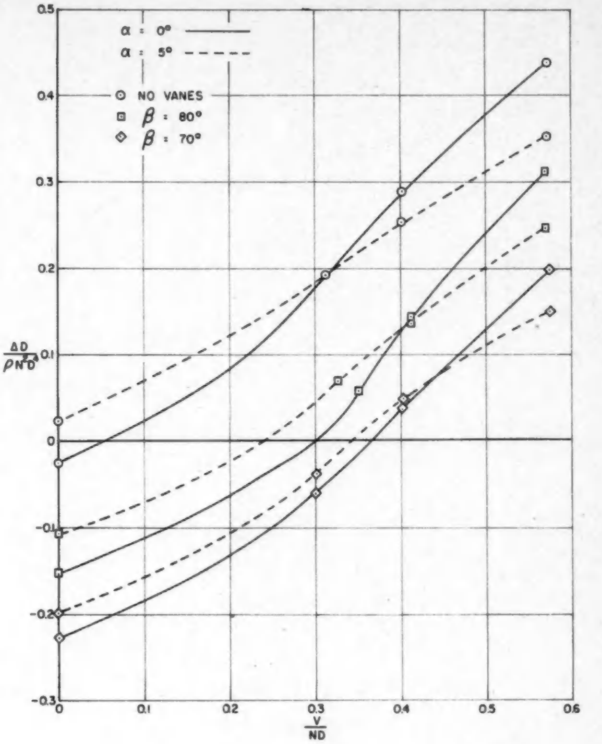


Figure 12
Drag vs advance ratio, rpm = 15,000

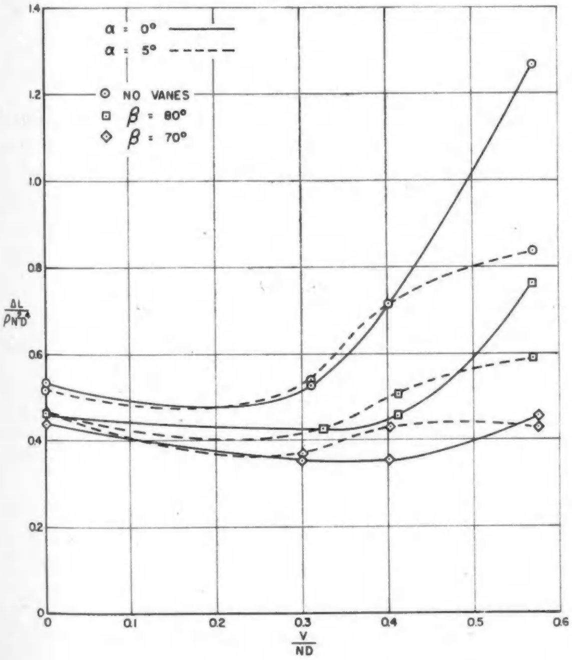


Figure 11
Lift vs advance ratio, rpm = 15,000

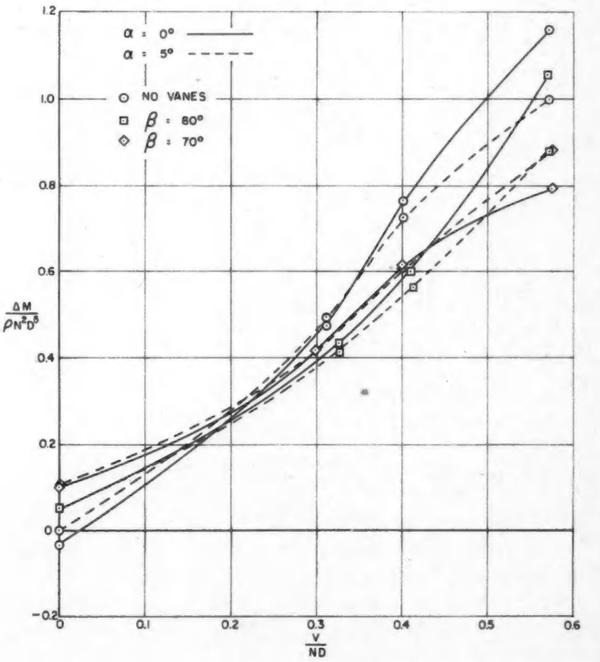


Figure 13
Pitching moment vs advance ratio, rpm = 15,000

of the order of 500 lb/ft². Figures 11, 12, 13 and 14 show the data plotted over this limited range for several outlet vane angles, β. The drag and lift curves illustrate the magnitude of forward thrust (negative ΔD) and the corresponding reduction of lift produced by deflecting the fan jet rearward.

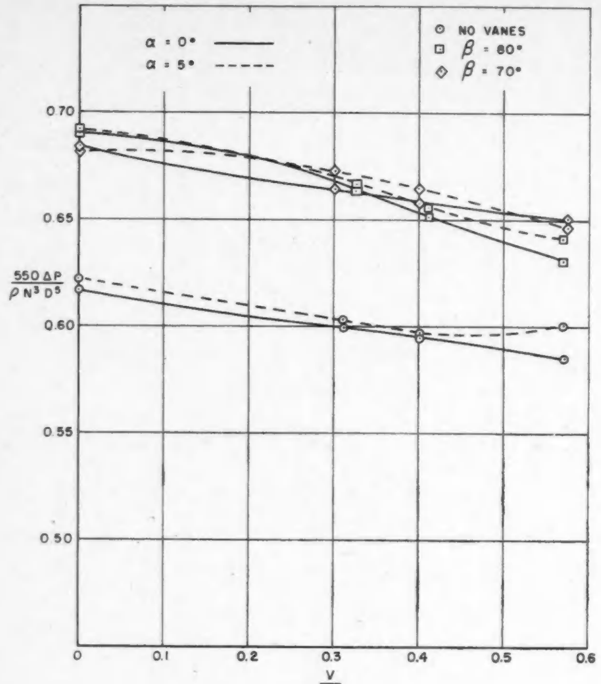


Figure 14
Shaft power vs advance ratio, rpm = 15,000

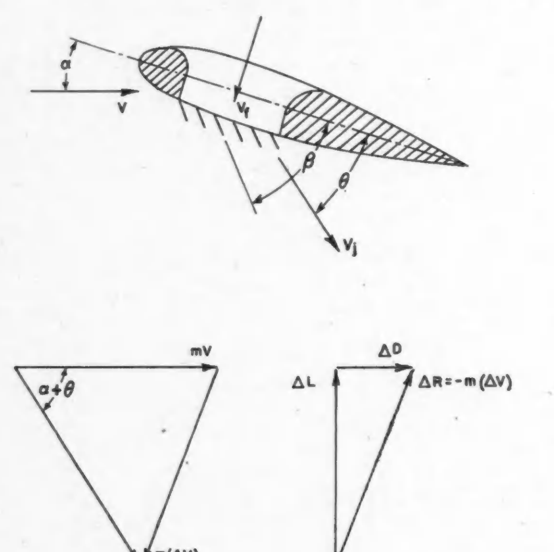


Figure 15
Momentum theory vector diagram

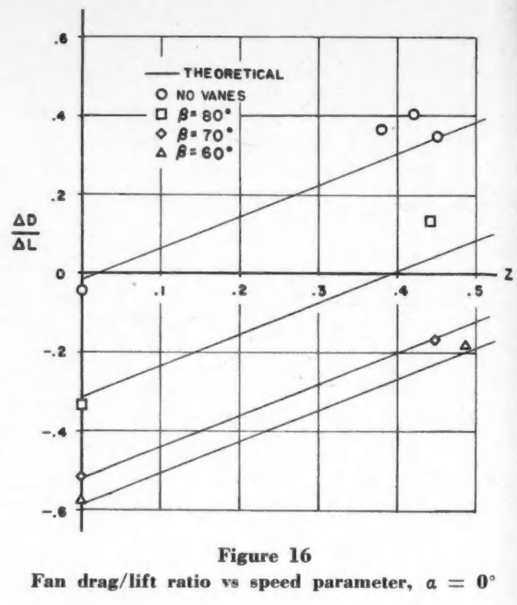


Figure 16
Fan drag/lift ratio vs speed parameter, α = 0°

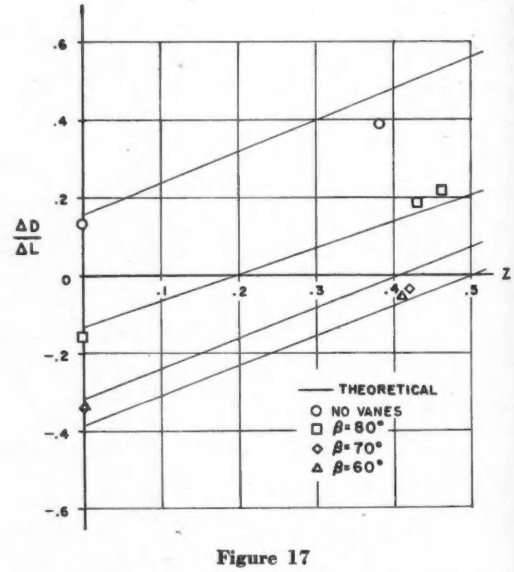


Figure 17
Fan drag/lift ratio vs speed parameter, α = 10°

THEORETICAL CONSIDERATIONS

The fan-wing model used in the test did not necessarily represent a practical design configuration. Therefore, in order to make use of the results in project studies of lifting fan aircraft it is desirable that they be compared with some reasonably simple theory. The theory need only be capable of predicting the fan drag increment as a function of fan lift and forward speed, since the necessary values of these latter quantities would be specified in a design study.

With reference to Figure 15, it can be seen that the force reactions on the model due to the momentum change of the air passing through the fan can be expressed as a function of angle of attack α, and the jet exit angle θ:

$$\Delta L = m\, V_j \sin(\alpha + \theta) \tag{1}$$

$$\Delta D = m\, V - m\, V_j \cos(\alpha + \theta) \tag{2}$$

and since

$$m = \rho A_a\, V_f = \rho A_a\, V_j \sin\theta \tag{3}$$

$$\frac{\Delta D}{\Delta L} = \left(\frac{V}{V_f}\right)\frac{\sin\theta}{\sin(\alpha+\theta)} - \cot(\alpha+\theta) \tag{4}$$

Using Eqs. (1) and (3) we can eliminate V_t from Eq. (4) so that

$$\frac{\Delta D}{\Delta L} = V\sqrt{\frac{\rho A_a}{\Delta L}\,\frac{\sin\theta}{\sin(\alpha+\theta)}} - \cot(\alpha+\theta)$$

Defining a dimensionless parameter $Z = V\sqrt{\dfrac{\rho A_d}{\Delta L}}$

we get $$\frac{\Delta D}{\Delta L} = Z\sqrt{\frac{A_a}{A_d}\,\frac{\sin\theta}{\sin(\alpha+\theta)}} - \cot(\alpha+\theta) \qquad (5)$$

Assuming that only the jet momentum forces contribute to ΔD and ΔL, the relation between α, θ and β has been determined from the experimental results for the case where $Z = 0$ (i.e. $V = 0$). It is found that for a given β, θ is independent of α and that for all α, β and θ can be empirically related, to a good approximation, by the expression

$$\theta = 59 + 0.0325\,(\beta - 59.6)^2 \qquad (6)$$

Experimental values of $\dfrac{\Delta D}{\Delta L}$ are plotted as a function of Z for several values of β and α in Figures 16 and 17, and compared with predicted values obtained using the theoretical equation for $\dfrac{\Delta D}{\Delta L}$ (Eq. (5)) and the empirical relation between θ and β (Eq. (6)). The comparison is satisfactory for low values of Z only. The failure of this relation at high values of Z implies that modifications of the aerofoil pressure distribution due to the presence of the fan produce an additional force on the model, or that the jet angle θ changes, for a given α and β, at high values of Z.

The expression developed for $\dfrac{\Delta D}{\Delta L}$ is suitable for project studies since it fulfills the requirement, pointed out earlier, that ΔD can be predicted, knowing ΔL and forward speed. Knowledge of rotational speed or fan exit velocity is not required. Also, it becomes evident that the transition phase can be completed within a range of Z where good agreement exists between experimental results and theoretical predictions.

From the same momentum considerations used in developing Eq. (5) an expression can be obtained for the power output of the fan system. Power is absorbed by accelerating the air through the fan and by developing thrust in the velocity direction:

$$550\Delta P = m/2/\,(\Delta V)^2 - (\Delta D)\,V$$

Defining a dimensionless power coefficient

$K_p = 550\Delta P\sqrt{\dfrac{\rho A_d}{\Delta L^3}}$ and again using Eqs. (1) to (3) we

obtain $$K_p = \tfrac{1}{2}\sqrt{\frac{A_d/A_a}{\sin\theta\,\sin^3(\alpha+\theta)}} - \frac{Z^2}{2}\sqrt{\frac{A_a}{A_d}\,\frac{\sin\theta}{\sin(\alpha+\theta)}} \qquad (7)$$

Theoretical values of K_p as computed using Eqs. (7) and (6) are compared (Figures 18 and 19) with experimental values of K_p determined using measured input powers. If one again assumes that only momentum forces act on the model, the comparison of theoretical values with experimental values only provides a measure of fan efficiency rather than a check on the validity of the theoretical development. On this basis, agreement between the two values should not necessarily be expected. However, the development can be considered of more than academic interest as it indicates a useful

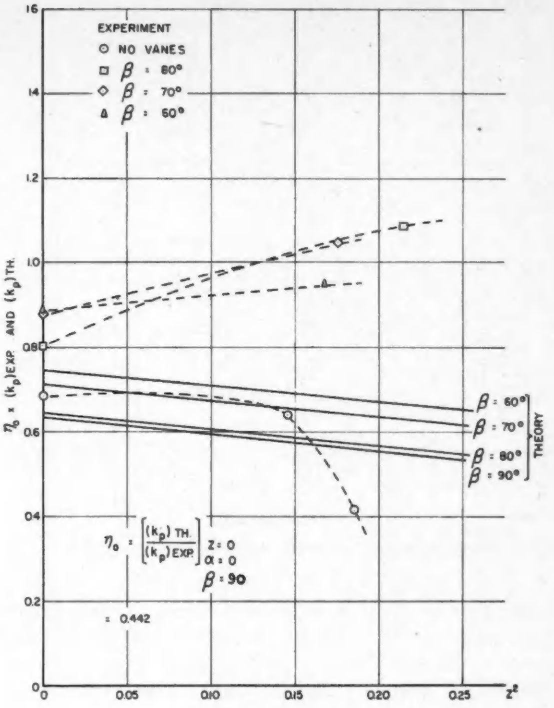


Figure 18
Power coefficient vs speed parameter, α = 0°

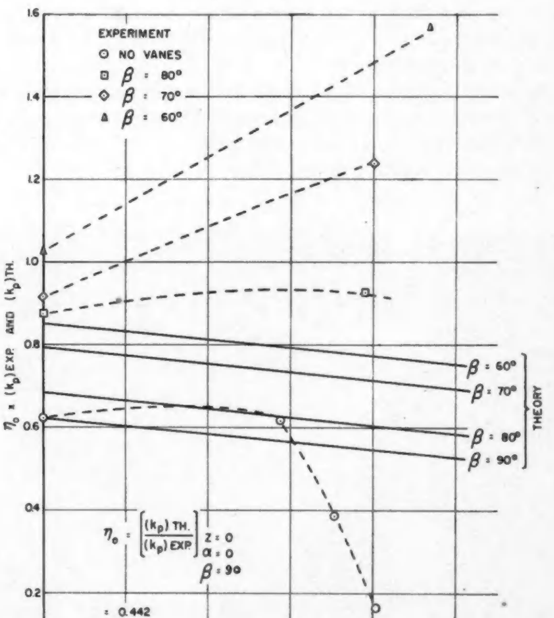


Figure 19
Power coefficient vs speed parameter, α = 10°

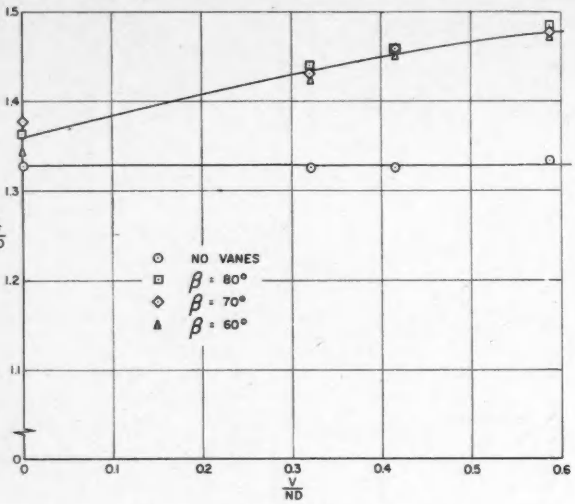


Figure 20
Fan velocity vs tunnel speed, rpm = 15,000

method of presenting a power coefficient for performance analyses. Using this presentation of experimental data, power input can be determined knowing only a required ΔL and the specified forward speed; no knowledge of rotational speed or fan velocity is required.

FAN EXIT VELOCITY

If there were any major changes of fan axial velocity with increasing advance ratio, it might help account for the large changes of ΔL and ΔD. Consequently fan exit velocity measurements were made. The measurements show that the velocity is independent of angle of attack and also indicate, as shown in Figure 20, that fan velocity changes by, at most, 10% over a large range of advance ratio. Therefore it can be concluded that this is not an important factor contributing to changes of ΔD and ΔL. Also, since the velocity change is small, it is equally appropriate to base the coefficients on fan tip speed as to base the coefficients on fan exit velocity.

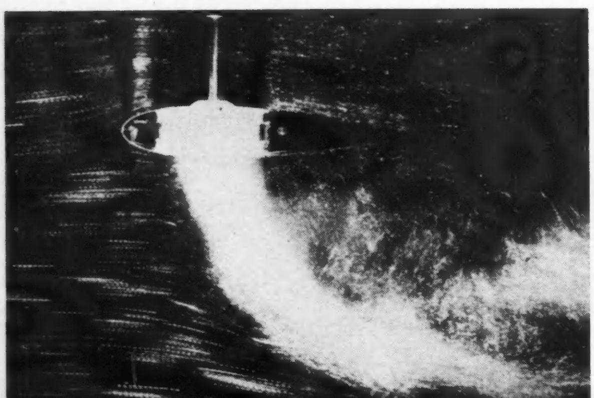


Figure 21
Water tunnel test
$\alpha = 0°$ $\qquad \frac{V}{ND} = 0.06$

WATER TUNNEL FLOW VISUALIZATION

It was thought that some knowledge of the flow pattern in the vicinity of the fan would be worthwhile in order to determine the nature of the interactions between the fan and the aerofoil, and thereby provide some understanding of the flow modifications that cause the large lift, drag, and pitching moment increments.

Such flow visualization is possible in the laboratory water tunnel. Fine aluminum particles suspended in the water are illuminated by a sheet of light provided by a mercury vapour light source and a cylindrical lens. The light source has a frequency of 120 cps so that when photographed individual particles in motion appear as a series of dots or dashes on the negative and their spacing provides a measure of particle speed.

A nine inch span scaled version of the wind tunnel model was installed in the water tunnel, and the small fan was driven by a shaft extending out through the top of the tunnel. The same advance ratio range was studied as with the wind tunnel model; the tunnel was run at constant speed and the advance ratio altered by changing the fan rpm.

Figure 21 is a photograph taken at an advance ratio of 0.06. A shift of the stagnation line along the wing lower surface is quite evident as is the consequent acceleration of fluid over the upper surface in front of the fan. Therefore the flow in front of the fan indicates a pressure distribution that would contribute to a strong nose-up pitching moment.

No quantitative studies of this flow field have been made to indicate the magnitude of lift forces and pitching moment. From consideration of mass continuity one

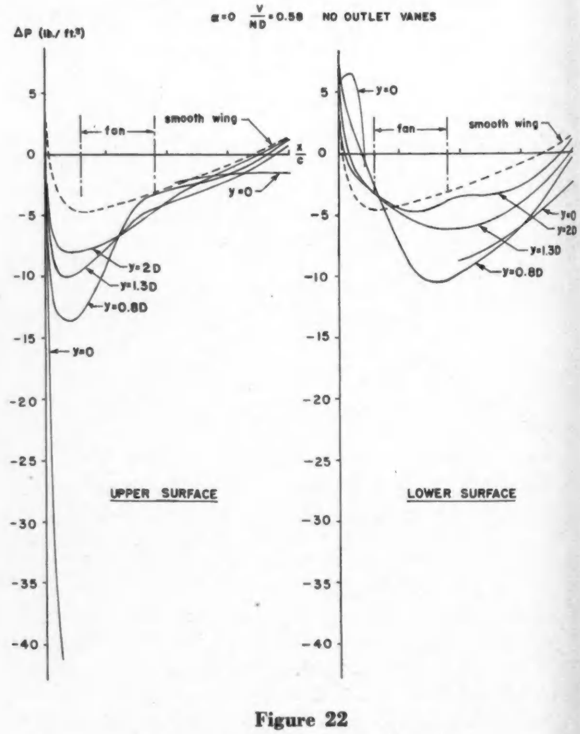


Figure 22
Pressure distribution near the fan

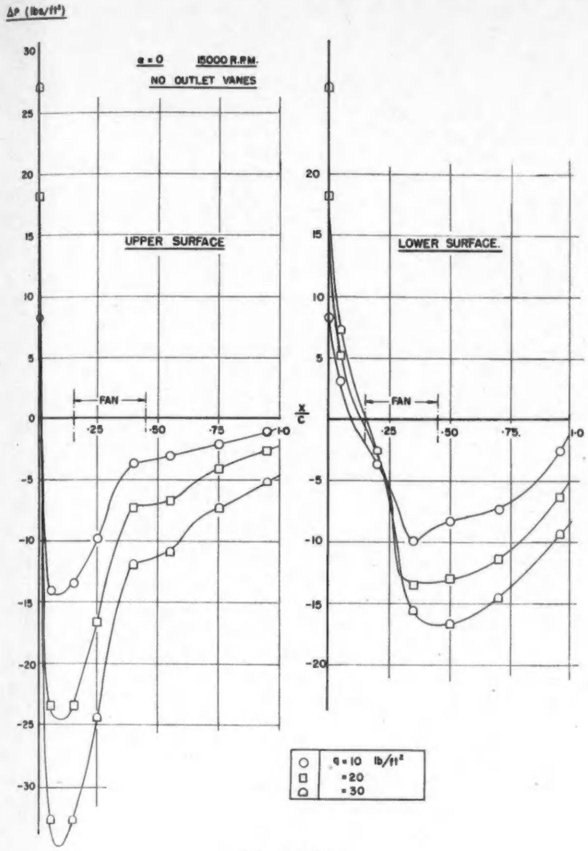


Figure 23

Chordwise pressure distribution near the fan, $\alpha = 0°$
Pressures at spanwise station 0.8 fan dia from fan centreline

can also see that the velocity behind the fan will increase on the lower surface and decrease on the upper surface, which would also contribute to a nose-up pitching moment.

SURFACE PRESSURE MEASUREMENTS

Surface pressure measurements were made to obtain a quantitative measure of the pressure forces on the wing. Plastic tube belts (see Figure 1), having 20 tubes each, were placed on the wing surface at several spanwise stations. About 14 static pressure taps were obtained at each spanwise station by drilling small holes in the individual tubes. This technique limited the number of pressure readings obtainable near the fan entry because of the sharp curvatures encountered there. This was unfortunate as the large pressure peaks diminish quickly with increasing distance away from the fan entry.

Figure 22 shows a typical set of pressure measurements. The suction peaks in front of the fan on the upper surface and behind the fan on the lower surface are quite pronounced. It is obvious that the pressures and pitching moments cannot be accurately integrated over the entire surface because of the lack of data near the fan hole.

Figures 23 and 24 show the data at higher wind tunnel velocities for the pressure belt nearest the fan.

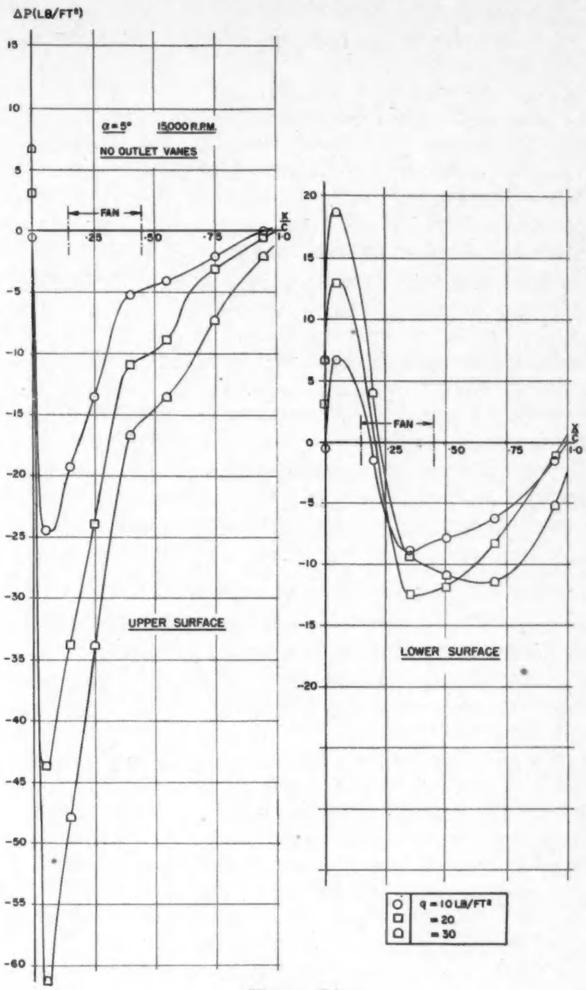


Figure 24

Chordwise pressure distribution near the fan, $\alpha = 5°$
Pressure at spanwise station 0.8 fan dia from fan centreline

Local values of lift and pitching moment can be obtained by integrating at this spanwise station. It is found that there is a sharp rise in lift with increasing advance ratio which qualitatively confirms that lift, over and above that predicted from momentum considerations, is obtained by this modification of the pressure distribution. Similarly the pitching moments can be accounted for by studying their variation with increasing advance ratio at this one spanwise station.

AIRCRAFT PERFORMANCE CONSIDERATIONS

A crude performance analysis can provide an insight into the behaviour and general characteristics during transition of a VTOL aircraft operating on the fan-wing principles discussed in the foregoing. Considering the requirement for a medium range transport, a simple example aircraft has been evolved.

Some details of the configuration studied are listed below:

(a) all-up weight = 28,350 lb
(b) wing aspect ratio = 7
(c) wing loading = 50 lb/ft²

(d) wing area = 567 ft²
(e) 8 fans driven by 4 engines
(f) fan diameter = 3 ft
(g) fan diameter/wing chord = 0.3
(h) fan pitch = 2.5 fan diameters (centre-line spacing)
(i) fan loading = 500 lb/ft² (based on disc area)
(j) engine design mass flow = 36.3 lb/sec
(k) engine sea-level static thrust = 2,720 lb
(l) $C_{D_o} = 0.023$
(m) Oswald's span efficiency factor, $e = 0.9$

From the ratio of wing loading to fan disc loading, the total fan area has to be 10% of the wing area. This is practicable on structural grounds for the assumed ratio of fan diameter to wing chord, although the increase in wing weight required to maintain the torsional stiffness of the original unperforated wing would be about 15%.

The analysis of transition flight used both experimental data and the previously derived momentum theory. Several simplifying assumptions were made:

(a) The momentum theory expression (Eq. (5)) and the empirical relation (Eq. (6)) were used to obtain $\frac{\Delta D}{\Delta L}$ in terms of α, β, and Z. For values of Z greater than 0.5 or 0.6 the linear relation is no longer adequate.

(b) The experimental K_p versus Z results as compared with theory provide an indication of the model fan efficiency and a measure of the power required by a fan-wing combination with increasing Z. Static results for ducted fans without outlet turning vanes reported by Krüger[2] lead to values of K_p as low as 0.6, whereas the momentum theory expression (Eq. (7)) gives $K_p = 0.625$ under the same conditions. For these reasons, the experimental K_p curves were factored by

$$\eta_o = \left[\frac{\text{theoretical } K_p}{\text{experimental } K_p}\right]_{\substack{\alpha = 0\\ \beta = 90\\ Z = 0}} = \frac{0.625}{1.412} = 0.442$$

and these factored results were used in the analysis. Whether this procedure can be justified is not critical to the analysis since its main effect is on engine size, and to study only transition behaviour no engine weight need be specified.

(c) No corrections for multi-fan interaction or for fan-fuselage interference were applied.

(d) No more than 30° backward deflection of the issuing fan jet need be assumed, since wind tunnel tests were limited to the range $60° \leq \beta \leq 90°$.

(e) All transitions were done at sea-level.

(f) The aircraft weight was assumed to remain constant during the transition.

(g) It has been assumed that static pitching stability can be obtained by a separate control system on a moment arm so long that the effect of control forces on lift and drag can be neglected.

The transition flight is based on the equations of motion

$$\frac{W}{g}\left(\frac{d^2z}{dt^2}\right) = W - \left\{qSC_L + 2E\,(\Delta L)\right\}$$

$$\frac{W}{g}\left(\frac{d^2x}{dt^2}\right) = T\,(4 - E) - \left\{qS\left(C_{D_o} + \frac{C_L^2}{\pi eA}\right) + 2E\,(\Delta D)\right\}$$

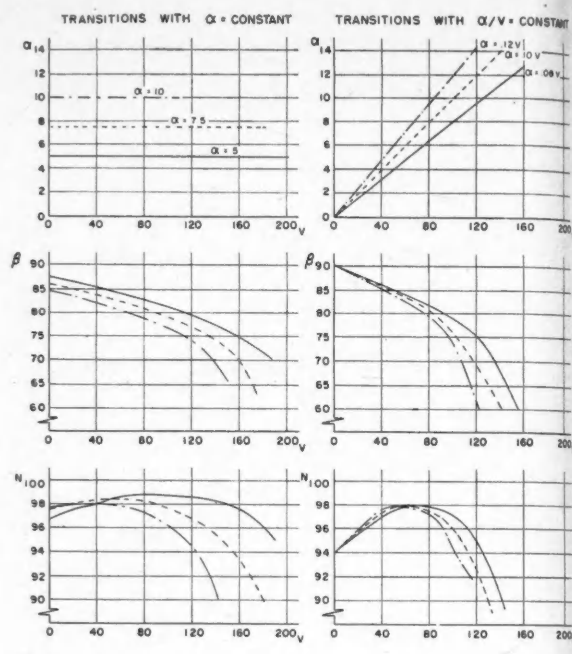


Figure 25
Eight-fan aircraft configuration
Equilibrium flight conditions—all engines "lifting"

together with Eqs. (5) and (6), the factored experimental results of Figures 18 and 19, and a set of assumed engine characteristics. The general solution of this problem is complex to a degree warranting the use of analogue or digital computing techniques, consequently the case where $\frac{d^2x}{dt^2}$ and $\frac{dz}{dt}$ are both zero and all engines are employed in the "lifting" mode will be dealt with here. With this restriction there are two independent variables; for convenience α and V were chosen.

Figure 25 presents three transitions at constant α and three with α proportional to V, while Figure 26 gives the α, β combination for maximum equilibrium velocity subject to limitations on N and Z. Obviously higher equilibrium velocities will exist if one engine or more is converted to direct thrusting duties, and flight at a high cruising speed with all fans shut down will be possible.

No consideration has been given to weight analysis of this configuration. However, the limited performance analysis demonstrates how the wind tunnel results can be applied, and also that high equilibrium velocities can be attained using the deflected fan jet alone to provide forward thrust. The analogue computer will permit the simulation of a complete transition, taking into account vertical and horizontal accelerations.

The aircraft configuration considered was restricted to a fan area equal to 10% of the wing area, which leads

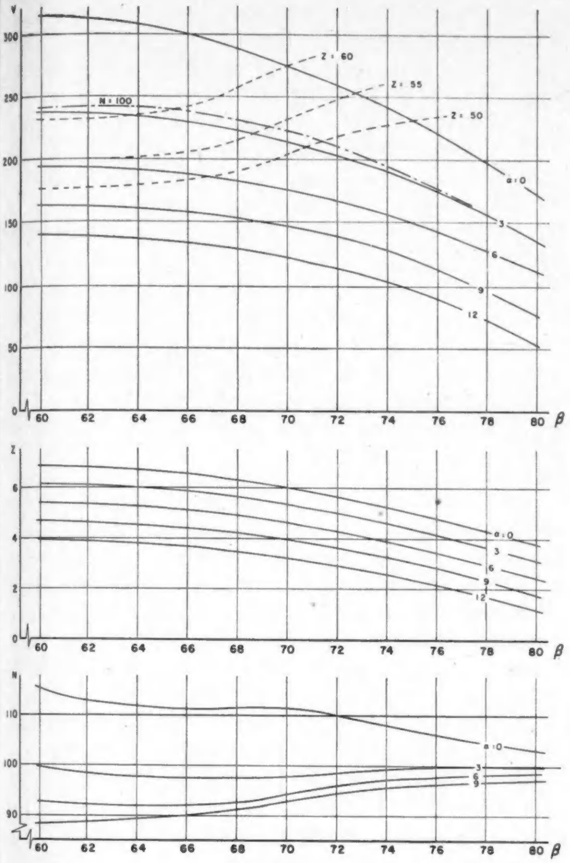


Figure 26
Eight-fan aircraft configuration
Equilibrium velocity—all engines "lifting"

to a required fan loading of 500 lb/ft^2. If a larger fan area and consequently a lower fan loading were permitted, the fan power loading $\left(\frac{\Delta L}{\Delta P}\text{ when hovering}\right)$ could be significantly reduced. This would result in a smaller engine installation and in improved power matching between hovering and cruising requirements. The dependence of power loading on fan loading is readily demonstrated by considering the power coefficient $K_p = 550\Delta P\sqrt{\frac{\rho A_d}{\Delta L^3}}$. This may be rewritten in the form $\frac{\Delta L}{550\Delta P} = \frac{1}{K_p}\sqrt{\frac{\rho}{\Delta L/A_d}}$ or $p_f = \frac{550}{K_p}\sqrt{\frac{\rho}{w_f}}$.

Therefore for a given power coefficient the power loading can be improved by reducing the fan loading.

CONCLUSIONS

Lift and drag forces on the model due to fan operation are not predicted by considering only the force reaction due to the momentum change of the air passing through the fan. Water tunnel flow studies and wing surface pressure measurements indicate that additional forces can be accounted for by considering the modifying effect of the fan on the aerofoil pressure distribution. These observations also account for the centre of pressure shift associated with the influence of the fan.

Fan output power in principle can be theoretically predicted from momentum and energy considerations, but to predict fan shaft power some knowledge of fan efficiencies is required.

Although lift and drag forces are not correctly estimated, the ratio of drag to lift can be accurately represented by the momentum theory over a range of the parameter $Z = V\sqrt{\frac{\rho A_d}{\Delta L}}$, adequate for the purposes of project studies of full scale aircraft using highly loaded fans. This permits the prediction of ΔD when ΔL is known, as would be the case for any project study.

Similarly, theoretical considerations provide a rational method of extrapolating measurements of shaft power to a full scale aircraft.

The experimental data are adequate for performance studies of a preliminary nature. However, a thorough study would require more detailed information, particularly about the geometrical factors such as the ratio of fan diameter to chord, the chordwise location of the fan, and the fan spacing in a multi-fan system.

Relaxation of the restriction that the fan area be equal to only 10% of the wing area would result in higher fan power loadings, with consequent reduction in engine size and improvement in power matching between hovering and cruising requirements.

REFERENCES

(1) Cockshutt, E. P. – *Dual-Operation Powerplants for Vertical Take-Off Transport Aircraft: A Preliminary Analysis of Several Gas-Turbine Cycles*, NAE Laboratory Report LR-201, 30 July 1957.

(2) Krüger, W. – *On Wind Tunnel Tests and Computations Concerning the Problem of Shrouded Propellers*, Deut. Luftfahrtforschung F.B. 1949, 1944: translation NACA TM 1202.

FUNCTIONAL MOCK-UPS FOR AIRCREW†

by Dr. M. G. Whillans*

Defence Research Board

INTRODUCTION

"*A truly functional design will be achieved only after it is thoroughly realized that the crewman is as much a part of the plane as any structural or mechanical feature.*"[1]

It may seem strange that it is necessary to repeat such a statement of the obvious, but it is still necessary, at least in Canada.

Everyone admits the need to consider the human element in designing aircraft and much attention is being given to human factors in specification and in design. In such matters as seat height, visibility from cockpits, placement of instruments etc, there has been considerable work and consultation with experts, usually late in the design and fabrication process. However, there has been little professional pre-planning of the human element in such systems, and no or little attention to the most critical problem of all.

THE PROBLEM

The main question facing us in any proposed new man-machine system is, "Will it do the job required of it?" Where an aircraft is involved there is generally immediate attention to thrust, weight and flight envelopes. The human element is still too often taken for granted. To the engineer it may seem rather foolish to ask what aircrew will be required to do, when he is not yet satisfied that he will get the contraption off the ground to make it a legitimate flying machine. Obvious matters like seat ejection, cockpit illumination and the provision of a galley are unlikely to be overlooked. What can easily be overlooked is the question of how well the crew will be able to do their jobs. I submit we have been looking at the fringes of the problem and have ignored this main question. Vigilance on such matters as seating comfort, oxygen supplies, cabin pressures, dials and controls will still be necessary and even vital. However careful we may be in seeking the ideal in such matters, making as few compromises as possible in each, the main question remains unanswered, "Will this man-machine combination do the job for which it has been designed?"

Unless we can bring together as many of the man-machine factors as possible before expensive fabrication is far advanced, and study them together, we shall certainly end up with an incomplete system and, perhaps even worse, we may never know how much and in what respects it has failed to meet its design requirements.

METHOD

The direct way to anticipate this problem is to use functional mock-ups. As soon as the general character of the aircraft design and the general nature of the crew's responsibilities are known, functional mock-ups should be designed and constructed. I use the word 'functional' to distinguish this type of mock-up from that made simply to ensure that the parts will fit together, and to enable the designers to better appreciate the three dimensions so that changes can be more readily planned. The functional mock-up type of study would go beyond this. It would permit the crew to do many of the tasks they will be required to perform in flight. The cabin pressure, temperature, lighting, ventilation, noise and possibly vibration would be as expected in the actual aircraft. If it is a long endurance aircraft, a galley, toilet and rest facilities would be provided. Work-rest routines would be studied for as long as typical flights would last. In addition, the effect of several time-on-duty time-off-duty periods on work efficiency could be studied. Excellent work along these lines is in progress in two or three laboratories in the United States. Studies have been made with space travel in mind. Also, some of you will be reminded of the famous Cambridge cockpit studies conducted under RAF FPRC auspices during and since the war[2]. These were mainly psychological in character. The proposal we are making is that the principle of studying the combination of physiological, human factor engineering and psychological factors in a simulated work situation should be applied to all new vehicles which may involve unknown or unusual stresses for the crew.

RESULTS

The study would necessarily be a complex situation with many variables, not all of them controllable. Scientists in laboratories could not be expected to rush eagerly into such work in the hope of publishing papers in the scientific journals.

What I am sure would happen during the studies is that various areas of difficulty would appear, each requiring some attention, just as they now appear during flight trials of new aircraft. While only rarely would a completely satisfactory solution be possible, a better

---

†Paper read at the Joint I.A.S./C.A.I. Meeting in Ottawa on the 7th October, 1958.

*Assistant Chief Scientist and Director of Biosciences Research.

compromise generally would be found, and in good time. Research and design development people would be brought closer together interpreting records, working out solutions and testing their solutions. A host of small 'fixes' would be made and many minor annoyances would be eliminated before the aircraft would be built.

The research man would discover longer-range problems suited to closely-controlled experiments. The development man would see a host of layout problems he could tackle for this and for other aircraft. Possibilities for retrofit in existing aircraft could be explored more satisfactorily.

AN IMAGINARY HISTORICAL ACCOUNT

Before going further, let me give you as an historical account the design history of the Odysseus, an aircraft which at the moment exists only in my imagination. By this means, nobody's feelings will be hurt as we recount the lessons which were learned during the creation of this successful aircraft, and there will be no need to rely on conventional memory. As Lewis Carroll's Queen said, "It's a poor sort of memory that only works backward".

Early in 1960, when the Canadian Government decided to proceed with the design and construction of the C-12X, now called Odysseus, the final proposal for an Arctic Inspection plan had just been approved at a Summit meeting. Owing to fore-sighted planning, the RCAF was quickly able to produce a detailed set of operational requirements for an aircraft suited to the needs of such inspection as well as to other purposes. Commercial interests had been consulted in this planning. The Odysseus has proven a versatile and popular aircraft in meeting Canadian and other needs, as its present manufacture under license in two other countries indicates. Its success may seem surprising, as the Odysseus is basically a conventional aircraft, as these figures show:

Span	140 ft
Length	100 ft
Takeoff weight (fully loaded)	110,000 lb
Runway length	3,000 ft
Pressurized	
Cruising speed	300-350 kts
Landing speed	110 kts
Range (max)	4,500 mi
Power	4 - 3,000 hp turboprop Frasers

The popularity of the aircraft, apart from its reliability and economy of operation, lies mainly in the unusually well-planned provisions for crew efficiency. Crew comfort and safety were also specified, but the emphasis in the specifications had been placed on *crew performance*. In anticipation of this particular requirement, the firm which made the successful bid had gathered a human factors team together, and in their bid a plan of study was outlined comprising the use of functional mock-ups.

The team comprised of one engineer who was also trained as an experimental psychologist, one part-time physiologist and one work methods specialist who was experienced in human factors engineering. This professional team was supported by an equal number of technicians, with extra technical assistance as work demands increased. Free use was made of outside consultants, and assistance on a number of special problems was provided by personnel and facilities of several Air Force, Defence Research and National Research laboratories.

Planning

The first task of this human factors team was to define as closely as possible the duties of each man on the aircraft, and the apparatus he would require. This proved rather difficult as no one could be definite about the details of many of the tasks which were anticipated.

Next, a simple plywood mock-up of the general layout of the aircraft interior was constructed, taking account of servicing and maintenance problems. The general size and location of each of the compartments was mapped out. Works layout techniques were applied and communication and crew movement paths in the aircraft were analyzed closely.

By this time, the design parameters of the aircraft were being more exactly defined and the general character of the aircraft had been determined. The aircraft was literally designed around the requirements for crew work. Through the early feed-in of information from the human factors team, an equivalent saving of 5 ft in fuselage length was found possible. This saving was particularly welcome to the engineers. Originally it had been intended to use piston engines, but there had been considerable worry that with them the noise levels would be above those specified, even with good sound insulation. The extra weight and space provided the required equivalent extra fuel capacity, and a switch was therefore possible to turboprop engines of slightly more power. By using contra-rotating propellers, a further reduction in predicted noise levels was achieved, particularly in the more troublesome higher frequency ranges.

The functional mock-up

The human factors team then turned its attention to the most urgent and most important problem. With more precise design parameters to work in, a more exact simulation of the fuselage interior was planned. A cabin differential pressure of not less than 10 psi was specified for the structure. The temperature range was to be 55°F – 80°F and humidities were requested from ½% to 30% R.H. Noise was to be applied through the fuselage wall by a variety of speakers. Overall sound levels of up to 120 db and limited ranges in octave selection were to be provided.

A revised description of the work required of each crew member and of the apparatus he would be using was prepared. Then, using a combination of the Cambridge cockpit principle, to provide recordable data and direct observation[2], and of modern simulator techniques, the functional mock-up was built. With it the most important studies related to the aircraft were performed. Each test crew was subjected, as a crew, to the various environmental factors which were expected in the aircraft. At the same time the test crews were required to perform their duties as assigned. Six different crews were passed through the test procedure, each for six test periods, making a total of 36 crew tests.

Results

The main results of these studies can be summarized briefly as follows:

(a) *Vigilance and accuracy*

There were significant decrements in vigilance and accuracy in tasks requiring close and skilled attention[3,4]. After the first thirty minutes, the accuracy of performance fell an average of 10%, and as much as 15% for some tasks. This was particularly evident with the navigator-radar operators and with the pilots. This decrement did not necessarily become worse during the following two hours. A closer study of man-machine relationships was then undertaken in conjunction with the U.S. National Bureau of Standards and the U.S. Air Force. Using the man-machine simulator developed by the Bureau of Standards, more precise estimates of the effects of the operator's performance on various otherwise automatic procedures were obtained, as well as data on how well the operators were doing their jobs[5]. This study allowed more precise planning of each job, especially certain specialized tasks in survey and inspection.

(b) *Fatigue*

Fatigue became increasingly evident to the observers and usually to the subjects themselves after six hours of close work. As fatigue progressed, the test subjects became increasingly willing to accept lower standards of performance. Less attention was paid to instruments not directly in front of the pilot or navigator, as if they were involuntarily reducing the size of their visual fields[2].

(c) *Night vs day flying*

Light and dark period simulated flights did not settle the question whether performance suffered due to disturbance of the 24 hr rhythm of body functions[6]. It appeared that greater stress arose from the extra vigilance and greater reliance on instruments which were necessary.

(d) *Boredom*

Boredom was not evident in the first few 'runs' with the test crews, but appeared later in the series, especially during transit times. It occurred during times off work and was accompanied frequently by restlessness and interference with sleep[7].

(e) *Hypnosis and preoccupation*

Signs of early hypnosis and preoccupation appeared during monotonous tasks, especially after the first hour when fatigue was becoming evident. These signs were sometimes evident in lack of prompt responses to signals, and in startle reactions with purposeless activity during simulated emergencies.

The crew were trained to understand these serious effects. The work routines were then altered to provide, where feasible, half-hour changes and sharing of duties. A more frequent alternation of monitoring responsibilities between pilot and co-pilot and between the navigator-radar operators effected a marked improvement in accuracy of work with less subjective fatigue. The mealtimes and coffee breaks were planned to assist in this respect.

(f) *Night vision*

The night vision of the forward look-out navigator was impaired unless the cabin was maintained at a simulated altitude of 5,000 ft or less. A further improvement in night vision was effected by breathing oxygen, and this was recommended for this position during night flights. At lower cabin altitudes, the general working efficiency and alert responses of all crew members were preserved for longer periods. A cabin altitude not exceeding 5,000 ft was therefore specified.

(g) *Noise*

There were some annoying localized high frequency noises, some due to background noise in earphones, others to faults in the ventilating system, which affected the performance of one of the special instrument operators who was required to have good pitch discrimination. It was found that pitch discrimination for higher frequencies was seriously impaired from the working efficiency viewpoint[3]. Removal of the cause of the noises was not always possible, but a marked improvement resulted from redesign of certain ventilation outlets and from better intercommunication equipment.

(h) *Cockpit displays*

The cockpit displays were subject to numerous changes during the study. A pictorial stylized map and aircraft attitude combined display and autopilot navigator for the pilot and navigator[9,10] proved to be a valuable asset, mainly as a check device and during low visibility conditions.

(i) *Monotony*

It was found that if too much reliance was placed on this system of instruments, the monitoring capacities of the human operators were dulled, apparently because of lack of enough interesting work. Accordingly, a number of tasks were assigned to each man to be done without the help of automatic instruments. In this way a reasonable work challenge was offered the crew and proved useful in reducing this danger. Transit times were particularly difficult periods to plan. They were eventually used to practise and improve aptitudes in inspection and in emergency procedures. By using prepared magnetic tapes, simulated signals were fed to the operators through their survey and inspection apparatus, and response timing and accuracies were measured. Each crew man was thus able to assess his own performance.

(j) *Air conditioning*

The chief problem proved to be the provision of adequate humidity. Unless cabin air humidity was maintained at or near 25% or more, the incidence of irritated, dry throats and noses was high. A simple light-weight humidifier was therefore installed in the ventilation system[6].

(k) *Miscellaneous*

Many minor problems were solved as they arose. The headsets proved to be unbearably uncomfortable after the first hour. A requirement for a better head-

set was restated, and a much lighter and more comfortable headset was produced. The parking brake handle was redesigned and relocated to provide a more effective pull. Annoying reflections at night on the windshield from illuminated dials were prevented. The bunks were fitted with reading lamps. The galley was equipped with a small refrigerator and a warming oven. Precooked, frozen foods were provided and, using the warming oven, full course hot meals were provided once a day in addition to a conventional breakfast and one light, cold meal with hot drinks.

(l) *Physical conditioning*

A detachable trapeze bar was fitted across the gangway to encourage simple exercises. It was reluctantly decided that a steam bath should not be provided, although the physiologist had shown that a compact one could be installed with small power and weight penalties.

DISCUSSION

The foregoing exercise in imagination provides a summary of the major problems which could be encountered in a large aircraft and of the methods which could be employed towards their solution. Every one of these problems as outlined exists in one or more of our modern aircraft flying today. None of the aircraft built in Canada has had an adequate, prior, systematic study of the operator's problems in each aircraft type.

If high accident rates due to human or pilot error continue, it is illogical and unfair to continue to blame the operator. We do not 'blame' the structural member of an aircraft if it fails from fatigue – we look to the designer for a solution. We should therefore look closely at the way the operator's job and the machine are designed. Aircrew themselves do not always help. They often feel responsible for making mistakes which basically are caused by design faults. Another point is that we should appraise not only what an airman can do but also what he thinks is worth doing. All these complex and often subtle problems are not easily foreseen *unless we test for them beforehand*. Functional mock-ups offer an obvious but neglected means toward a better operational result.

CONCLUSION

In order to save time, money, and expensive and often unsatisfactory retrofits, man-machine problems can profitably be studied using the functional mock-up as a tool. Human efficiency can thus be studied objectively and directly in relation to the specific machine system. Means towards the preservation or improvement of the efficiency of the operator can be studied and tested before translation into the final design of the machine.

ACKNOWLEDGMENTS

The assistance of many colleagues and friends in the Defence Research Board and in the Royal Canadian Air Force is gratefully acknowledged.

REFERENCES

(1) McFarland, R. A. – *Human Factors in Air Transport Design*, McGraw-Hill, 1947.
(2) Davis, D. R. – *Pilot Error*, Air Ministry, AP 3139A, London HM Stationery Office, 1948.
(3) Mackworth, N. H. – *Researches on the Measurement of Human Performance*, MRC 268, London HM Stationery Office, 1950.
(4) Bartlett, F. C. – *Fatigue following highly skilled work*, Proc. Roy. Soc. London, SB 131 (864) 247.
(5) *Man Machine Simulation System*, Technical News Bulletin, US National Bureau of Standards, Vol. 42, p 68, April, 1958.
(6) Whittingham, Sir Harold – *Medical Research on Flight Time Fatigue*, FPRC 1037, Air Ministry, January, 1958.
(7) McFarland, R. A. – *Human Factors in Air Transportation*, 1st Ed. McGraw-Hill, p 326, 1953.
(8) *Research on Auditory Problems Presented by Naval Operations*, RCN Medical Research Division, J. Cdn. Med. Services, 3, p 323, May, 1946.
(9) Hoover, G. W. – *Instrumentation for Space Flight*, J. Avia. Med., 28, p 495, 1957.
(10) Fogel, L. J. — *Keys to Better Cockpit Display*, Aviation Age, p 32, July, 1958.

TECHNICAL FORUM

Manitoba Government Air Service

A summary of a talk by J. Uhlman, Director, Manitoba Government Air Service, delivered before the Winnipeg Branch on the 27th January, 1959

Mr. Uhlman introduced his talk by describing Government Air Service since its origin to its present status. It was started in 1932 by a group of ex-RCAF pilots using two Vickers Vedette biplanes purchased from the RCAF. The original group using these machines were primarily concerned with Forest Fire Control work, and little expansion was made until after World War II. During World War II, Government Air Service was at its lowest level since its inauguration, consisting of 3 aircraft and a staff of 6. As the Service was expanded to meet other Government departmental requirements, cabin aircraft were purchased, the first being a Fairchild FC-2 powered by a Wright engine. Since then, this type of equipment has been used and, at present, the fleet consists of 8 De Havilland aircraft (6 Beavers and 2 Otters). To employ the staff during the break-up seasons, the policy of doing their own maintenance and overhaul work was introduced. This has been expanded until, with very minor exceptions, the operation is self-sustained.

Mr. Uhlman was extremely proud of the high level of maintenance obtained and the general condition of the aircraft, taking into consideration that machines land, on the average, every 60-odd miles either on pontoons or rough snow. Modern headquarters and maintenance hangars have been built at Lac du Bonnet where all aircraft and engine overhaul is carried out. Two aircraft are stationed at The Pas on a year-round basis. A summer base is maintained at Norway House and a winter base in the Thompson River area to be of maximum service to mining and other crews operating in northern Manitoba. Bush flying of this type is strictly on visual flight rules, the pilot relying on his maps, compass and knowledge of the country.

Manitoba Government Air Service provides transportation and communication for a number of Provincial Government departments. They maintain, as part of their operation, 400 radio communication sets and, up to the present, have built most of this equipment. They also have 100 mobile units which can be moved to any operation centre. Mr. Uhlman then went on to deal specifically with the work carried out in each department.

Fishing Branch

Transportation of Inspectors to commercial operations throughout the northern lakes, to ensure fishing regulations are met and that fish meet the requirements of the Health Standards. To meet the Dominion health requirements, lakes are sampled regularly to ensure that fish are not contaminated. Transportation of fish eggs from the Clear Water Lakes to the fish hatcheries and the transportation of trout fingerlings from various hatcheries to sporting lakes in the Whiteshell area are one of the last and first jobs undertaken in the fall and spring.

Forest Branch

Forest work utilizes ⅓ of the operational aircraft, which are employed in fire detection and supervision. Once a fire is detected, fire fighters are flown to small lakes as close to the area as possible to permit effective fire control. The Government Service developed the system of dropping 50 gallon plastic water bags on small fires. This was reasonably effective and has been improved upon by the Ontario Government by the mass drop methods. Transportation of Fire Wardens from Winnipeg to various stations is also a major undertaking carried out by this Department. Transportation of construction materials for towers, timber cruisers, and insect infestation inspections are jobs which are the responsibility of the Air Service.

Game Branch

Some years ago, Manitoba introduced a registered trap line system whereby groups of trappers in various districts mutually agreed to work prescribed areas, usually defined by natural barriers such as streams or rivers. These trap lines are registered and periodically the trappers are gathered together for meetings or discussions. The picking up of trappers and bringing them to some central location is done by the Government Air Service.

The destruction of timber wolves is also a major undertaking in the winter. Deer or caribou are killed and the meat poisoned. Carcasses are then cut up and distributed to various lakes and later on the aircraft return to pick up the dead wolves. This type of work is extremely hard on the aircraft since it is taking off and landing on rough snow continuously all day. Also, the fresh meat steams up the interior of the cabin and windows making it an unpopular job with the pilots. Aerial Game census are carried out for the deer and caribou population as far as the Northwest Territory border; live beaver are transported from crowded streams to more remote areas.

Lands Branch

A considerable amount of aerial survey work is carried out for this department.

Mines Branch

During the summer, exploration field parties are flown to various locations with their equipment. They are maintained during the summer by aircraft and brought out in the fall.

Survey Branch

During the winter, the Government survey parties are employed cutting survey lines in the northern part of the province. This is an important part of the northern development programme, to permit the location of mining claims, timber development etc. At present, these parties are working along the northern boundaries of Manitoba. The practice is to establish a camp and as the cutters move forward they are returned by aircraft to the base camp each night. Every 5 or 6 days the camp is moved forward to keep headquarters in close proximity to the actual working parties. Transportation of men to the cutting areas and the moving of camps is one of the duties of the Air Service. This type of taxi service of about 5 minutes duration is extremely hard on aircraft. The main aircraft base and camps are at Lynne Lake and the aircraft leave each morning and night for the various lakes for this work.

Water Resources Branch

Hydrographic survey work is being carried out on a large number of northern rivers to ascertain Hydro potentials of this area. Aircraft are almost steadily employed during the winter, flying in crews to various areas employed in this work. These camps have to be maintained by aircraft and a certain amount of reconnoitering is carried out to assist the ground parties. Also, the altitude of all lakes in the area must be measured and this is usually done by flying in engineers, who determine the level of the lake above sea level and the surrounding rivers.

A number of other Government Departments use the aircraft as a means of communication. Government officials visiting some outlying area, the flying in of prisoners and the return of ex-prisoners to their northern homes, mercy flights for the Department of Health and Welfare, telephone and power line inspection are all in a day's work for the Government Air Service.

The aircraft average approximately 350 to 400 hrs per year in the air and this utilization is being steadily increased by the establishment of overlapping bases to the north which will eventually permit year-round operations. Approximately 27 gas caches are maintained in the north for winter operation. Gas is transported whenever possible in the summer by boats and in the winter by tractor train.

Winnipeg — G. Milner

REPRINTS OF PAPERS

Published in the Canadian Aeronautical Journal
can be obtained at the following rates

Length of Paper	1 to 4 pages	5 to 8 pages	9 to 12 pages	13 to 16 pages
100 copies	$18.00	$25.00	$33.00	$42.00
Additional 100	$4.50	$7.50	$10.50	$13.50

Orders for reprints should be addressed to the Secretary within 30 days of the date of issue of the Journal in which the paper appears. Orders for less than 100 copies cannot be accepted.

INSTRUCTIONS TO CONTRIBUTORS

The Canadian Aeronautical Institute invites the submission of papers, articles and technical notes for publication in the Canadian Aeronautical Journal. Following the practice of other societies, the Institute does not pay for contributions.

Authors should prepare their material in accordance with the following directions:

Manuscripts. Manuscripts should be
(a) Typewritten, double-spaced,
(b) On one side of 8½ x 11 white paper,
(c) With wide margins, approximately 1½", and
(d) With pages numbered consecutively.

Manuscripts must be in final form; the addition of material after acceptance by the Institute cannot be permitted.

Titles. The following form should invariably be adopted:—
(a) Titles should be brief;
(b) The name and initials of the author should be written as he prefers; (Rank or title preceding the name e.g. Wing Commander or Dr., should be included but abbreviations of degrees etc., after the name, should be omitted.);
(c) The name of the organization with which the author is associated should be shown under his name; and
(d) The author's position in the organization, referred to in (c) above, should be shown as a footnote to the first page.

Summaries. Each paper should be preceded by a summary
(a) Of 100 to 300 words, (10 to 35 lines, double-spaced),
(b) In non-specialist language, so far as possible,
(c) Stating the main conclusions of the paper.

Sub-Headings and Paragraph Numbering. Sub-headings should be inserted by the author at frequent intervals. Paragraphs should not be numbered.

References. References referred to by the author should be treated thus:—
(a) References should be numbered consecutively throughout the paper;
(b) An allusion to a reference should be indicated by a bracketed numeral e.g. "It has been shown by Dr. T. T. James (7) . . .";
(c) Direct citation of a reference in the text should be written in full, e.g. "As shown in Reference (7) . . ."; and
(d) References should be grouped together in numerical order at the end of the paper, each showing
first, the numerical designation, e.g. "(7)".
second, the author's name, e.g. "James, T. T."
third, the title of his work, e.g. "Aerodynamics and Ballistics"
fourth, the title, volume, issue no, and date identifying the publication in which it appeared, e.g. "R.B.S. Journal, Vol. 7, No. 77, July 1907".
Thus "(7) James, T. T.,—Aerodynamics and Ballistics, R.B.S. Journal, Vol. 7, No. 77, July 1907."

Footnotes. Comments on or amplification of the text should be given in footnotes, appearing at the bottom of the appropriate pages.
(a) Footnotes should be designated alphabetically and consecutively throughout the paper; and
(b) A reference to a footnote in the text should be indicated by a bracketed letter, e.g. "omitting consideration of the third power (c) . . ."

Figures, Tables and Equations. Reference in the text to
(a) Figures and Tables should be given in full, e.g. "Figure 7", but
(b) Equations should be abbreviated to Eq., e.g., "Eq.(7)" or "Eqs.(5) and (6)".

Drawings. Drawings should be
(a) Individually identified by Figure or Table number,
(b) Not larger than 12" x 16",
(c) In black ink on white paper or tracing cloth, and
(d) Capable of being reduced to 3½" wide without loss of legibility of lettering or other detail.

Photographs. Photographs should be
(a) Black and white, glossy prints, and
(b) Individually identified by Figure number, written on a separate piece of paper affixed to the back: writing on the back of the photographs should be avoided.

Captions. Each Figure and Table should be identified by a caption, in addition to its number, e.g., "Figure 12 Theoretical lift distribution".
(a) The caption of a Table should be shown at the top of the Table;
(b) The caption of a Figure should be shown preferably outside the boundary of the Figure; and
(c) A complete list of Figure and Table captions should be given on a separate sheet of the manuscript.

Mathematical work. Only the simplest mathematical expressions should be typewritten; others should be carefully written in ink. Mathematical work should be
(a) Uncrowded—plenty of space should be provided to accommodate directions to the printer—,
(b) Repeated on a separate sheet of the manuscript, again uncrowded and with plenty of space around each expression,
(c) Clearly written to distinguish between like symbols. e.g. between zero and the letter 'o', and between Greek and English letters of similar form, and
(d) Accompanied by a manuscript "index" of the Greek letters used in the paper, identifying each letter by a name, e.g. "α—alpha".

In addition the following practices should be adopted:
(a) Simple fractions appearing in the text should be shown with a solidus, e.g. A/(B+C) rather than as

$$\frac{A}{B+C}$$

(b) Complicated expressions should be identified by some convenient symbol, if necessary to avoid repetition of the whole expression; and
(c) Complicated subscripts and exponents, and dots and bars over letters or symbols should be avoided.

Symbols and Abbreviations. Consistency is important;
(a) The symbols recommended in the American Standards Association "Letter Symbols for Aeronautical Sciences" ASA Y10-7—1954 should be used wherever practicable; and
(b) Abbreviations of units should be shown in lower case without periods, e.g. lb, mph, bhp, etc.

Mailing. Papers should be mailed to The Secretary, Canadian Aeronautical Institute, Commonwealth Building, 77 Metcalfe St., Ottawa 4, Canada.
(a) Drawings and photographs may be mailed rolled or flat, not folded;
(b) Manuscripts should be mailed flat.

C.A.I. LOG

SECRETARY'S LETTER

PROGRAMME AND PLANNING

We are now approaching the end of the active season of monthly Branch meetings and so forth and, although there will not be much of a lull in our programme until June, it is not too early to begin thinking about next year. In April and May the new Executive Committees of the Branches will take office and during the summer months they will be planning their programmes. I am sure that they would welcome suggestions from their members. Now is the time for every one of us to look back over the past season, while it is fresh in our minds, and try to think of ways in which it might have been improved.

When a Branch Annual General Meeting is over, all of us, including the newly appointed Executive Committee, are tempted to sit back and do nothing until late July or August. Then begins a general scramble to line up a speaker for September and thereafter the programme is liable to be built up in a hand-to-mouth fashion, because things have been left too late for any real planning. Moreover those responsible for the programme have had no opportunity to consult the membership and, in any event, the membership has given no thought to the subject and has forgotten its "beefs" about the season before.

Let us all try to do better this year.

What else?

And this applies not only to the ordinary programme of Branch meetings but to other activities as well. The Ottawa Branch has set up an Education Committee – nothing to do with the Institute's Provincial Committees – with the idea that it should investigate the feasibility of organizing courses of lectures for the members of the Branch. These lectures would be quite distinct from the monthly meetings; they would be more like "evening classes" and those enrolled would pay a small fee for each course. (At least this is my understanding of the proposal.) I cite this as an example of the sort of activities that Branches might explore.

I feel sure that many members have ideas about ways and means by which the Institute could serve them better. Those responsible for our programmes are inclined to be too close to the problem and they would welcome suggestions (sensible suggestions!) from others with a wider perspective.

This invitation for suggestions is not confined to Branch activities. I know that the Council's Planning Committee would welcome ideas about the expansion of the Institute's services as a whole.

PRODUCTION SECTION

We ran a notice in the December issue about the proposed Production Section; we were anxious to assess the demand for such a Section and we did, in fact, get a few replies – I should have liked a few more.

I must confess that the proposal is hanging fire, largely due to my inability to visit Toronto (where it originated) to talk it over with the moving spirits. The preparations for the Special Anniversary Meeting last month and the coming Annual General Meeting in June have kept me pinned down to Headquarters. I mention this now to reassure the many members whom I know to be interested that I have not forgotten about their Production Section and will get around to it at the first opportunity.

STAFF

Mr. W. A. Chisholm joined the staff as Assistant Secretary, in the middle of February. He arrived just before the Special Anniversary Meeting; it was a little like the arrival of Blücher at Waterloo but I was awfully glad to see him.

I hope that all our members will get to know him well and that, with his help, we shall be able to give you better Headquarters' service.

BRANCHES

Montreal

Reported by I. S. Macdonald

January Meeting

W/C C. R. Thompson chaired the meeting held on the 21st January and explained that the planned speaker for the evening, Mr. J. Dancik of the Vertol Company, was unable to arrive in time for the meeting due to poor weather.

Mr. J. T. Dyment introduced Dr. G. S. Hislop, Chief Engineer of the Fairey Aviation Company, and explained that Dr. Hislop had accepted a last minute invitation to talk about the development of the Fairey Rotodyne.

Dr. Hislop introduced first some of the drawbacks of the current helicopters, namely that they are too slow, too small and too costly to maintain for intercity operation. The reason he gave for the slowness of the conventional helicopter was the fact that the rotor must supply all the thrust, lift and control of the aircraft. This imposes a high load on the rotor and the speed is therefore limited by the tip stalling of the blades and consequent vibration.

The design of the Rotodyne was conceived to relieve the rotor of its heavy work load by first providing a wing to absorb much of the lift in cruising flight. Secondly, engines were installed to provide thrust so that in normal flight no thrust is required by the rotor. Thirdly, manoeuvering control is supplied through an empennage of a conventional type.

Dr. Hislop pointed out that the Rotodyne design combines the characteristics of a helicopter at takeoff, landing and hovering conditions, plus the advantages of conventional aircraft facilities of wing, propellers and tail control in normal flight. In this way, it is hoped that the speed of the aircraft will reach 150 kts.

The problem of providing a power of 6,000 to 8,000 bhp into the big rotor would have been extremely difficult and costly if done by normal means. The size and complexity of the transmission would have offset many of the advantages of the design. Dr. Hislop then discussed the design and development of the pressure jets at the tips of the rotor blades. Air from the engine is fed through the rotor blades and fuel is supplied also through the blades to a simple pressure jet on each tip. These jets drive the large rotor at high speed and thus develop the high power necessary for takeoff and hovering. During normal flight the rotors are not driven but merely form wind-milling drag.

Dr. Hislop then showed an excellent colour film of the development work and flight testing of the Rotodyne. His running commentary of the testing of the many components gave clear evidence of the great amount of research that was necessary prior to the first flight of the aircraft.

The subject promoted several interesting questions regarding the payload, weight, cost and development aspects of the Rotodyne.

W/C Thompson thanked the speaker for a most interesting talk. Forty-five members attended the dinner. Several members from the newly-formed Student Section were also in attendance.

Halifax-Dartmouth

Reported by Lt. J. A. Turner

January Meeting

The monthly meeting of the Branch was held in the cinema of the Chief Petty Officers' Mess, HMCS Shearwater, on Thursday, 22nd January. A total of 41 members and guests were present.

The Chairman read from the report of the Fiftieth Anniversary Committee in the absence of the Committee Chairman, Mr. R. Wallworth, who was absent through illness. The report outlined the arrangements for a commemorative banquet, marking the Fiftieth Anniversary of the first aeroplane flight in Canada, which will be held on the 23rd February in the Nova Scotia Hotel, Halifax. The special guest speaker for the banquet will be Mr. D. O. Turnbull, who is the son of Dr. Rupert Turnbull. Dr. Turnbull is noted in the field of aviation as having built one of the first wind tunnels in the world, in 1902, and developed the first variable pitch propeller. Special guests at the banquet will include the Lieutenant-Governor, Major General E. C. Plow, Heads of the Armed Services for the area, and the Mayors of Halifax and Dartmouth.

The speaker for the January meeting, Mr. J. H. Evans of Cossor (Canada) Limited, was introduced by Mr. W. J. Robinson.

Mr. Evans presented a paper on "Electronic Aids to Navigation". In the introduction he indicated the basic problems of aircraft navigation and how these problems could be solved by various basic navigational methods and aids.

Mr. Evans reviewed the basic carrier wave theory and, with the aid of an oscilloscope, gave a visual demonstration of some of the principles used in electronic aids. He discussed in considerable detail various guidance and ranging systems currently available and under development, outlining their operating principles and specific application in the navigation field.

In conclusion it was noted that, although numerous aids were available, the systems used would vary depending on the role of the aircraft and the weight penalty involved. This latter consideration would be of prime importance to the commercial operator.

After a brief intermission, a very interesting and invigorating discussion period followed, during which the speaker answered questions presented by the members and guests. The speaker was thanked by Lt. D. G. Morris.

Winnipeg

Reported by G. Milner

January Meeting

The fourth meeting of the Branch was held in the Westinghouse Auditorium on the 27th January. It was addressed by Mr. J. Uhlman, Director, Manitoba Government Air Services.

The speaker was introduced by Mr. B. W. Torell, Vice-Chairman of the Branch, who told briefly of Mr. Uhlman's experiences as a pilot in World War I, subsequent flying experience with the RCAF, and finally his taking over and establishing the Government Air Service in 1932.

(*Mr. Milner's summary of Mr. Uhlman's lecture is rather long for this section of the Journal but it is of considerable interest and is reproduced in full in the Technical Forum on page 114. – Sec.*)

The speaker was thanked by Mr. D. A. Newey for a very interesting and entertaining evening. The meeting concluded with two films, "Mapping of Northern Manitoba" and "Fishing".

Vancouver

Reported by G. W. T. Roper

January Meeting

On Wednesday, 21st January, 24 members participated in a conducted tour of No. 5 Air Division Combat Operation Center. The tour was under the

direction of S/L L. E. Evans, Duty Operations Officer.

Within limitations necessary for security reasons, S/L Evans outlined how Division 5 and other similar Divisions were organized and their affiliation with NORAD and the Air Defence Command. The functional, geographical and political aspects of this phase of defence were also outlined in special detail to enable those in attendance to understand the tremendous task of organization and control required to safely guard the North American continent.

It is practically impossible to give a detailed account of all that transpired during this tour but it can be said, on behalf of those present, that the tour was well organized and most informative.

Calgary

Reported by H. E. Hampshire

February Meeting

A Dinner Meeting was held on Tuesday, 10th February, at the Al-San Club in downtown Calgary. Forty-one members and guests were in attendance, a commendable effort considering the outside temperature of nearly 20° below.

Models of the Silver Dart and the Arrow were on display to commemorate the Golden Anniversary of Flight. These models were fabricated by the aviation students at the Institute of Technology and Art in Calgary. Their efforts in this regard were greatly appreciated by all.

The Chairman, Mr. W. A. B. Saunders, opened the meeting by introducing members and guests at the head table. A short business session followed at which time it was learned that F/L E. Erhart will be leaving this area in early summer.

The guest speaker of the evening, Mr. A. L. Sutton, Service Manager of Orenda Engines Ltd., was then introduced by S/L M. R. Barrett. Mr. Sutton opened his talk on the Iroquois turbojet engine by some brief references to the earlier developed Chinook and Orenda engines. In 1953 the Iroquois was designed and quickly backed by the Hawker-Siddeley group. Although actual performance figures are classified, Mr. Sutton explained that this engine was in the 20,000 lb thrust category and left no doubt in the minds of the audience as to its potential. Design features, such as the thrust-weight ratio, two spool compressor preference and graphs illustrating specific fuel consumption, pressure ratio, specific thrust and combustion temperature at varying Mach numbers were shown on projected slides and explained in detail by Mr. Sutton. After dealing with certain of the newer types of material used in construction of the engines, the speaker concluded his address by outlining the various stages of development testing carried out. Mr. Sutton was thanked by F/L Erhart on behalf of the Branch for his most interesting and informative address.

The guest speaker was followed by the showing of a film "Supersonic Sentinel", an excellent although brief account of the design, manufacture and initial test flying of the Avro Arrow.

Ottawa

Reported by R. L. Wardlaw

Special Meeting

A special meeting was held on the 2nd February at the RCAF Gloucester St. Officers' Mess. The special meeting was called since the Branch had the opportunity of being addressed by Mr. J. Lukasiewicz. Mr. Lukasiewicz is a former Secretary of the Ottawa Aeronautical Society and was a member of the Interim Council of the CAI. He is now in charge of the Gas Dynamics Facility of ARO, Inc., near Tullahoma, Tenn.

The Branch Chairman, Mr. H. H. Kelland, was in the chair and he introduced our guest speaker. Mr. Lukasiewicz spoke on "Experimental Investigation of Hypervelocity Flight". Before getting seriously into his subject matter, Mr. Lukasiewicz showed a short movie entitled "Samba" which demonstrated in a novel, entertaining style, the capabilities of helicopters. With the audience now in a more receptive mood, the speaker outlined experimental techniques which are now being developed for hypervelocity investigations in relation to characteristics of trajectories of interest. The problems of shock tube tunnels, piston-compression tunnels, Hotshot-type tunnels, aeroballistic ranges and free flight were considered. The electric-arc method of heating air to drive wind tunnels (Hotshot-type) is being used at ARO, Inc., and these facilities were discussed in detail and a motion picture was presented showing the equipment and its operation. 16 inch and 50 inch diameter tunnels are in use and velocity simulation up to Mach 8 and Mach number simulation up to Mach 10 can be realized.

An interesting question period followed the talk and Mr. Lukasiewicz was thanked by Mr. R. J. Templin. Thirty-seven members and fifteen guests were present.

February Meeting

The regular February meeting was held on the 11th February in the RCAF Beaver Barracks and Mr. Kelland was chairman. G/C E. P. Bridgland introduced the guest speaker, Mr. R. D. Hiscocks, the Chief Design Engineer of De Havilland Aircraft of Canada Ltd. Mr. Hiscocks spoke on "Design and Development of a STOL Aircraft".

The Company's experience with utility and STOL aircraft leading up to the conception of the Caribou was outlined. The ability of a utility aircraft to operate in undeveloped areas with no established airfields was stressed. For this type of operation, ruggedness and reliability are of unusual importance and, consequently, where possible, the use of proven components is desirable. This was a factor in the selection of the Pratt & Whitney R-2000 engine, which not only has established reliability but is in wide use throughout the world, thereby alleviating the maintenance problem. In order that the aircraft attract a wide market, the aircraft has to be extremely versatile and capable of both civil and military application.

With the above considerations in mind, the problems associated with the evolution of the final Caribou design were discussed. The talk was concluded by a discussion of the STOL performance of the aircraft.

Following a lengthy question period, Mr. Hiscocks was thanked by Mr. J. A. Dunsby. Forty-six members and eight guests were present.

BRANCH STUDENT AWARDS

In the November 1958 issue of the Journal we announced the forthcoming scheme of Student Competitions and Awards, which at that time was starting to take shape, with several Branches having submitted their proposals for Council approval.

Members will be interested to know that the following schemes have been approved for the Student Award competitions, to take place at the various educational institutions within the area of each Branch.

Calgary

Provincial Institute of Technology and Art

For the best technical report. These reports will be assessed by a panel of judges made up from the Aeronautics Department and the English Department of the PITA in cooperation with the Calgary Branch of the CAI.

Halifax-Dartmouth

Nova Scotia Technical College

For the highest standing in the subject of Fluid Dynamics in the final year of Mechanical Engineering.

Montreal

Loyola College
McGill University
Sir George Williams College
University of Montreal

For a paper having a topic related to aeronautics, and the winning candidates delivering their papers orally. The awards will be divided into two parts:

(a) The best paper from each of the aforementioned educational institutions.

(b) The top paper selected from those in (a) above.

The panel of judges will consist of representatives from industrial and educational facilities in cooperation with the Montreal Branch of the CAI.

Toronto

University of Toronto

For the three best theses by aeronautical engineering students, based upon assessment of the content and oral presentation, by the Toronto Branch of the CAI.

Ryerson Institute of Technology

For the best technical report. The top three reports being submitted to the Toronto Branch Committee for selection of the winner.

Central Technical School

For the best general academic record during the final two years of the Aircraft Mechanics Course.

Vancouver

Canadian Services College, Royal Roads

For an Essay on a specific aeronautical engineering subject, selected by the Vancouver Branch Executive who will review the papers and choose the winner.

Winnipeg

University of Manitoba

For a thesis based on an aeronautical subject, with evidence of experience or intensive study in some phase of the aeronautical sciences, to be judged by the University of Manitoba in cooperation with the Winnipeg Branch of the CAI.

MEMBERS

NEWS

Dr. A. M. Ballantyne, Hon. F.C.A.I., was recently named a Fellow of the Institute of the Aeronautical Sciences.

B. J. Kaganov, A.F.C.A.I., was a recipient of one of this year's B'nai Brith awards to outstanding Jewish figures in the arts and sciences.

LCDR G. M. Cummings, M.C.A.I., has been transferred from HMCS Bonaventure to the Naval Aircraft Maintenance School, Shearwater, as the Training Officer and Deputy Officer-in-Charge.

W. A. Chisholm, M.C.A.I., formerly with Canadair Ltd., has joined the staff of the Canadian Aeronautical Institute as Assistant Secretary.

P. Y. Davoud, M.C.A.I., a Director and Vice-President of Orenda Engines Ltd., was recently appointed to the position of Chairman, Air Transport Board.

G. B. Rayner, M.C.A.I., formerly Superintendent of Maintenance, Maritime Central Airways, is now employed as Chief Aircraft Inspector, Dept. of Transport, Ottawa.

B. W. Spacey, Technical Member, has left Canadair Ltd. for a period of one year with Boeing Airplane Co., Seattle.

R. E. Stoddart, Technical Member, has left the Northwest Industries Ltd. to join the staff of the Institute of Technology and Art in Calgary in the capacity of Instructor, Aeronautics Dept.

DEATH

It was with deep regret that we learned of the death in December of **G. W. Bath, Technical Member,** who was a Draftsman with Avro Aircraft Ltd.

AWARD TO PROFESSOR LOUDON

The Professional Engineers Medal, presented by the Association of Professional Engineers of the Province of Ontario for Outstanding Achievement by one of its members, was awarded to Professor T. R. Loudon, Hon. F.C.A.I., at the Annual Meeting of the Association on the 24th January. This is only the seventh time that the Medal has been awarded since it was introduced in 1946. The award was made to Professor Loudon "for a valuable contribution to the Professional and Educational Life of his country" and we feel sure that his many friends in the Institute will agree that it was well and truly deserved.

Professor T. R. Loudon (l) receiving the Professional Engineers Medal from Mr. C. T. Carson, President (1958) of the Association of Professional Engineers of the Province of Ontario

As a young man, Professor Loudon was a classmate of the Hon. J. A. D. McCurdy and the late Mr. F. W. (Casey) Baldwin at the University of Toronto. In 1910, he helped to organize the first air meet held in Toronto – at Trethewey airfield in Weston. And in 1926, he formed the COTC flying club at Leaside airfield in suburban east Toronto. He holds a private pilot's licence and still manages to get in some flying time despite his age.

During the winter of 1935-36, he told an audience at the Royal Canadian Institute that it wouldn't be long before people would be able to fly from Toronto to Winnipeg and return in the same day. The audience, he recalls, thought this was a huge joke.

At the beginning of World War II, Professor Loudon, on loan from the University of Toronto to the RCAF, organized the Aeronautical Engineering School at Montreal, and later took over command of the Test and Development establishment at Rockcliffe where all types of planes were tested and modified and where vital gunnery and radar installations were carried out.

He retired from the university in 1954 after 47 years of teaching there and is in a consulting capacity position with the De Havilland Aircraft of Canada Ltd.

SUSTAINING MEMBERS

NEWS

The Bristol Aeroplane Company of Canada Ltd. has announced a reorganization of the Company, whereby it will be known in future as Bristol Aero-Industries Limited and the former Companies of Bristol Aero Engines Ltd., Bristol Aircraft (Western) Ltd. and Bristol Aero Engines (Western) Ltd. will be known as the Montreal, Winnipeg and Vancouver Divisions, respectively.

Computing Devices of Canada Ltd. announce that their Skyline navigation system is to be marketed internationally by the Bendix Aviation Corp. and the Bendix Radio Division has been licensed to manufacture the equipment.

Skyline is a dead-reckoning navigation system developed to meet the requirements of commercial airlines. Inputs from the gyro compass and doppler radar are fed to an 8 lb electromechanical analogue computer. The computer continuously computes the position of the aircraft with respect to a pre-selected track, and presents to the pilot his position in terms of miles from start or last turning point, miles to destination or next turning point, and miles right or left of track.

Use of a coordinate system, based on the track required rather than on the more conventional latitude and longitude grid, leads to many advantages. The pilot is often less concerned with his latitude and longitude, though this can easily be obtained if needed by reference to a map. In high latitude operation, this feature makes it possible to use an arbitrary gyro direction reference rather than north.

In normal flying, the Skyline computer is coupled to the automatic pilot, thus providing automatic course corrections. Should a pilot be forced to deviate from his track by a storm, the automatic pilot and Skyline combination will take him back to his track in an optimum approach. Returning to track in an optimum approach is automatically accomplished by computer signals to the autopilot. When flying on track, the Skyline provides automatic course corrections to the autopilot.

In the event of doppler failure, Skyline continues to provide navigational information based on the last found drift and ground speed until a change in course is made. With an optional Wind Triangle Computer, the wind speed and velocity are continually available to the pilot or navigator, and if the doppler fails the system continues to operate as a pure dead-reckoning system using the last found wind. This Wind Readout feature is expected to be of great value to meteorologists, since aircraft will be able to report winds conveniently and accurately without plotting or calculation from any part of a flight.

Skyline is made up of three separate units weighing in total less than 15 lb. Heart of the system is the computer, which is a standard ½ short ATR rack mounted unit. The other two units are cockpit instruments. The Computer Control Unit displays Track Angle, Distance Gone from 0 to 999 miles, and Offset Left or Right from 0 to 99 miles. The Pilot's Indicator indicates Relative Track, Offset, and Distance to go from 0 to 999 miles.

Canadair Ltd. successfully flew the first pre-production "Canadair 540" on the 2nd February and the second is scheduled to fly in March. Both aircraft are to be handed over to the RCAF and the third will be held indefinitely by the Company for test and demonstration purposes.

The 540 is a two-engine medium-range propeller turbine transport, designed for use in military, commercial and executive versions. It has capacity for 58 passengers. The pre-production aircraft, Convair-built airframes converted by Canadair for power by British-built Napier Eland turboprop engines, have been given those assignments pending the delivery of the 540 aircraft from the Montreal company's own production lines. The RCAF has already ordered 10 in the military version.

The military version will be built primarily as cargo-carriers but will be easily convertible to passenger use, or a combination of passengers and cargo, when necessary. The RCAF has designated the type "CC-109". In commercial versions the planes are being offered in world markets in passenger, cargo, convertible and executive configurations.

In addition, Canadair has a program to convert Convair 340 and 440 aircraft, now in commercial or executive service, to Eland turboprop engines.

It is also announced that Canadair Ltd. has introduced an unusual feature in the CL-44G Transport; the tail unit is hinged and is capable of being swung back to expose the entire fuselage cross-section for cargo-loading.

It may be of interest to compare this swing-tail aircraft with naval aircraft design. There, the folding of the wing, a primary structural member, is accomplished under much more severe conditions than those attending the rear fuselage break. Naval fighter aircraft are designed to higher load factors – hinges and actuators are closely confined in a thin wing, making the problem more complex. Their problem is also one of space, as controls, hydraulics, fuel lines and electrical leads must all pass through the break-line.

The swing-tail has two large external hinges on the right hand side of the fuselage 90° apart and a hydraulic actuator between them to open and close the fuselage. Locking is accomplished by nine equally spaced latches which are designed to transmit fuselage tension and shear loads.

The hinges, actuator and latches are backed up by stiff structural members, frames, longerons and intercostals, all designed to give a rigid structure and keep deflections to a minimum. An inflated seal all around the joint is provided to prevent leakage of cabin pressure.

Some of the features of the latches are: the handles, which are recessed in the structure, can only be pulled by squeezing a release lever, so inadvertent movement of the mechanism is ruled out. As a further safeguard, a double action latch has been provided; the first 45° movement of the handle moves the hook about ¼ inch horizontally away from the latch pin while still keeping the shear pins engaged; the last part of the handle movement lifts the hook clear of the pin, allowing the joint to separate. If there is tension on the joint, then it is impossible to initiate the second motion of lifting the hook clear of the pin.

As a fail-safe feature, each lock is designed to carry a 50% overload in order to allow for complete failure of any one hook, in which case its load will be shared by the two adjacent hooks.

In addition to these basic safety features, an electrical system of micro-switches and interlocks is provided to safeguard against selecting takeoff power unless all latches are secured. When opening the rear fuselage, operation of the actuator is locked out until all latches are free.

Deflection, sag, and the matching of the two sections of the fuselage have been fully investigated. Fuselage and

frame deflections at the break have been calculated under all conditions up to and including a 60 mph wind from any direction with the fuselage open. The maximum deflection under this very severe condition is approximately $\frac{1}{2}$ inch vertically at the side opposite to the hinges. This is taken care of by a spigot and roller system designed to align the two halves of the fuselage during closing. There is a chamfer of $\frac{1}{8}$ inch on the shear pins at each latch to take care of local frame deflections (which are actually less than 1/16 inch).

For initial alignment and adjustment during overhaul, the hinges and latches are adjusted by means of serrated plates, and the tension in each latch is accurately set by means of eccentric latch pins.

The method of locking the fuselage by the nine separate latches is considered the simplest and most positive approach. Fully automatic hydraulic locking systems can be designed to do the job, but it is not felt that the time saved during each operation will justify the extra complexity, expense and weight.

Four different methods of breaking the control runs have been investigated. The one selected consists of providing bevel gear boxes and at each side of the fuselage break. These convert the rotary action of the torque tubes to oscillating motion of a pair of levers, one on each side of the joint. The levers transmit the control movement across the joint by direct contact when the fuselage is closed, and merely separate on opening – no connections or locks are necessary. The gear boxes are the same as those used in the Argus to convert the pilot's control movements to rotary motion of the torque tubes. Generous bearing areas are provided to allow for all possible misalignment. Torque tube splines and universal joints permit adjustment of the contacting parts.

The levers on the forward part of the fuselage are recessed to protect them from damage, and the mating parts on the rear portion are protected by a protruding box structure.

The CL-44 control surface gust-locks are retained on the CL-44G.

In so far as transmitting the other services across the joint – electrical, hydraulic, anti-icing etc. – no serious problems exist. On the original CL-44 tail, anti-icing is accomplished by a separate combustion heater in the tail fuselage section; therefore, only a minor modification to the fuel supply line across the joint is required. The same applies to the electrical and hydraulic system lines and is accomplished with flexible joints at the hinged portion of the break.

D. Napier & Son Ltd. has announced the formation of a Canadian subsidiary to handle their growing business in aero and diesel engines in Canada. The new company will be known as D. Napier & Son (Canada) Ltd. and will have its head office at 4104 St. Catherine St. West, Montreal. Its principal object is to sell Napier's products; to make contracts with customers for the overhaul of Napier engines; to sub-contract the overhaul and servicing of Napier engines, and to provide and distribute spares.

In the aeronautical field the company will be chiefly concerned with the installation of the Eland propeller turbine in civil and military versions of the Canadair 540, with the conversion of piston-engined Convair airliners to Eland power, with civil and military applications of gas turbines in helicopters, with rocket engines and the Napier Spraymat system of de-icing.

De Havilland Aircraft of Canada Ltd. announce that, after six months intensive test flying with the first two aircraft, changes in the dimensions and weight of the DHC4 Caribou have been introduced to improve the payload and carrying capacity, while still retaining the remarkable short takeoff and landing performance.

The gross weight has been increased from 24,000 to 26,000 lb, which provides a greater payload. The aircraft will be certificated at this higher gross weight and will fully meet the requirements of CAR Part 4B.

To accommodate the bigger load, the cabin has been lengthened some 45 inches to a length of 28 ft 9 inches, providing space for another row of passenger seats, which increases the total to 30. The cargo capacity is similarly increased. Increased capacity improves the loading configuration for both passengers and cargo.

Despite the increase in size and weight, the outstanding STOL performance of the Caribou has not been sacrificed. The high rate of climb and excellent single engine performance are also retained.

BOOKS

Fundamentals of Advanced Missiles. By R. B. Dow. John Wiley & Sons, Inc., New York, 1958. 567 pages. Illus. $11.75.

Rapid development has taken place in the field of jet-propelled and guided missiles during the last few years. Because of the great diversity of components, functionally interrelated, which must be combined in a compatible way to form a working system, a book which gives a comprehensive treatment of the subject and its fundamentals involving propulsion, aerodynamics, guidance and control of missiles must be more than welcome. It is the author's aim to fill an evident gap in this respect with a single volume introduction to the subject. The title "Advanced Missiles" has been chosen, though the main emphasis is on guided missiles, in order to make it clear that the applicability of the basic principles outlined in this book also extends to long range ballistic missiles, earth satellites, and space vehicles.

To fulfil its aim, the book treats in 9 chapters: (1) the fundamentals of kinematics of flight, (2) fluid mechanics, with its application to aerodynamics and including thermodynamics and heat effects, propellants and combustion, (3) dynamics, with aerodynamic forces and moments, equations of flight, dynamic stability, launching and control of missiles, (4) applications of probability and statistics, including reliability and quality control, (5) properties of microwaves, (6) infrared radiation, (7) radar, (8) guidance, and (9) the concept and engineering considerations of guided missile systems, with a view to missile and overall system factors.

All these topics are treated concisely, with the main objectives of "presenting the subject in a logical rather than in a formal manner", and "indicating the interrelationships between similar or related subjects". Since the book condenses so many and diverse subjects into one volume, experts in a special field may not always agree with the presentation of this subject, but this does not affect the general usefulness of the book. There are also various misprints – which are often unavoidable in a first edition – and these may sometimes be confusing for the beginner,

mainly in the mathematical parts and, for example, regarding vector notation. All this, however, can be eliminated in a following edition.

It is interesting to note that the book, with 555 pages of text (excluding the attached index) contains 860 footnotes, 202 figures and tables and 1,052 formulae. The great number of footnotes, although perhaps distracting, reflects the author's desire to be accurate in every aspect and to give explanations and references to the reader who wants to supplement his knowledge. Even the larger number of formulae confirms the fact that the reader of a technical book should always be equipped with a pencil! This is particularly true for this book. However, it is doubtful whether a reader not fully acquainted with the elementary backgrounds of the several subjects would always be able to follow the treatise so easily as, for example, on some topics in the Dynamics chapter. This, on the other hand, is an advantage insofar as the reader is forced to study the book very thoroughly in order to "write his own ABC" of the subject.

In general, the book is most valuable for engineers wishing to acquire a sound background of the basic principles in all fields related to missiles, the various functions of a system and the requirements for their combination to a properly working unit.

Dr. H. J. Luckert

Aircraft and Missile Propulsion, Vol. II. By M. J. Zucrow. John Wiley & Sons, Inc., New York, 1958. 636 pages. Illus. $13.00.

This volume, the second of a three volume work on aircraft and missile propulsion, deals with methods for the analysis and determination of the performance characteristics of thermodynamic propulsion engines. The six hundred page text encompasses five chapters, beginning with a discussion of gas turbine powerplant cycles and followed by separate treatments of turboprop, turbojet, ramjet and, finally, rocket jet engines. The work is aimed primarily at the engineering graduate student and practising engineers who are not specialists in propulsion, and is designed to furnish them with an understanding of the basic technology of these engines.

The excellent format of Vol. I is continued in the present book. Each chapter is preceded by a complete nomenclature, points in the text are admirably reinforced at every opportunity by illustrative worked out problems, the many figures are of uniform design and of unusually high quality (with the added advantage of appearing at the most convenient places with reference to the text), and each chapter is concluded with a good bibliography of relevant unclassified material. It is probably in the area of organization of his material that the author has scored his greatest success.

The contents follow the usual lines in which the effect of separate variables on everything else is traced, in apparently inexhaustible detail, over a spectrum of circumstance ranging from the ideal to the practical. The resulting vast mass of data is presented with such clarity, however, that the author's objective is surely achieved and it seems safe to predict that the complete work will acquire the status of a somewhat expensive necessity of life for graduate students of propulsion systems for some time to come.

R. A. Tyler

The Silver Dart. By H. G. Green. Brunswick Press Ltd., Fredericton, N.B., 1959. 208 pages. Illus. $4.95.

It was with no small degree of pleasure that I noted from this book's sub-title, "The authentic story of the Hon. J. A. D. McCurdy, Canada's First Pilot", that someone had finally written a book on the life of a man who has become something of a legend in this country. The first few chapters of the book on the early life of the young Douglas McCurdy certainly seems to point up the fact that truth can at times be stranger than fiction.

In the account of the early years of the young Douglas McCurdy, it is possible to feel the effects of that dominant personality Alexander Graham Bell. I felt much better though when it was finally acknowledged in the book that Bell was, like the rest of us, a human being with human faults.

The formation of the Aerial Experiment Association in 1907 was possibly one of the most unique cooperative efforts of all time, but one finds little mention of their various sources of inspiration with regard to the problem of flight. Certainly Bell's years of kite experiments do not seem to have led the group too far astray. In an earlier book, "Alexander Graham Bell" by Catherine Mackenzie published in 1928, there is the suggestion that Octave Chanute's classic book was their principal source of reference material. Mr. Green's book appears to have one of the most extensive accounts of the A.E.A.'s activities that has so far appeared in print, but he has used the word "first" much too freely.

The account of that history-making flight at Baddeck in the Silver Dart gives us a wordy picture of the McCurdy who had become one of the foremost flyers of that time. Some of the most interesting reading is found in the descriptions of McCurdy's barnstorming flights in the U.S.A. in the years 1910 and 1911.

While the author's style of writing and choice of words seems unsuitable in places, his choice of illustrations has been good. Of special note are the photographs of "Baddeck No. 1" and "Baddeck No. 2".

The appendices at the end probably have the most controversial material in the whole book. This is particularly true of McCurdy's address advocating the formation of an English-speaking federation of the world. In the biographical sketch on "Casey" Baldwin, I looked in vain for some mention of his work with hydrofoils.

Finally the index appears to be quite a useful one for those who have need of such things, and in general the book is well produced.

C. J. Toms

Flying Witness. By G. Wallace. McClelland & Stewart Ltd., Toronto, 1958. 262 pages. Illus. $5.00.

Mr. Wallace bases this book on the reports and recollections of Harry Harper and it covers many of the notable flights and air meets between 1906 and 1914. Mr. Harper was appointed Air Correspondent by the "Daily Mail" of London in 1906.

In this position he was privileged to observe the early balloon flights and the development of the heavier-than-air aircraft in Europe as well as to know many of the early pilots and constructors. In consequence, while the events in the book have been told before, they take on a new interest owing to the close acquaintance Mr. Harper had with many of the people concerned.

However, the book devotes its main attention to events occurring prior to 1912 and the events from 1912 to the beginning of the war are only allocated about 24 pages. This is somewhat disappointing as, for example, the Schneider Trophy events of 1913 and 1914 are covered in a sentence and a paragraph respectively. This apparently reflects the Daily Mail's stories of these events.

This book should provide interesting reading to all, and especially to those in the aviation industry. For those more deeply concerned with historical aviation matters, it will provide a useful complementary volume to R. Dallas Brett's "History of British Aviation".

K. M. Molson

APPOINTMENT NOTICES

The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No., to which enquiries may be addressed (c/o The Secretary), will be assigned to each notice submitted by an individual.

The Institute reserves the right to decline any notice considered unsuitable for this service or temporarily to withhold publication if circumstances so demand.

Position Required

Box 106 **Technician:** Seeks position as Powerplant Technician. 17 years' experience covers supervision of maintenance, test and instrumentation of various types of piston and gas turbine engines. Also experience with test cells and flying test beds.

Positions Vacant

Mechanical Engineer: To supervise small precision machine shop. Must have (a) Higher National Certificate, or equivalent; (b) 20 years' practical experience in small organization and fully conversant with aircraft materials and standards; (c) ability to estimate and process machinery operations; (d) design and supervise manufacture of jigs and fixtures; (e) drive and ability. Apply in writing to the General Manager, Canadian Flight Equipment Cobourg Ltd., 66 Swayne St., Cobourg, Ont.

Aircraft Publications Staff — *Technical Author (Mechanical), Parts List Compiler, Technical Illustrator*: Required by an aircraft repair and modification plant in Edmonton, Alta. Applicants must have had at least 3 years' experience in aircraft publications work. Good salaries plus re-location expenses in approved cases. Medical and hospitalization benefits plus a Pension Plan after qualifying period. Write giving full particulars of age, education, qualifications, experience and salary required to the Industrial Relations Manager, Northwest Industries Ltd., P.O. Box 517, Edmonton, Alta.

Trainees: From time to time we have openings for young men 17 to 25 interested in careers in aviation to participate in our trainee programme. Applicants should have eleventh grade education, although this is not essential, and must be mechanically inclined. Trainees are employed in our shops while taking international correspondence schools course at home. Good pay – cost of course by payroll deduction with rebate upon successful completion. As courses are in English, applicants must be English speaking or completely bilingual. Apply in writing to: Personnel Manager, Aircraft Industries of Canada Ltd., P.O. Box 100, St. Johns, P.Q.

EDUCATION AND TRAINING

Ontario Department of Education

The Correspondence Courses Branch of the Ontario Department of Education has drawn attention to its Vocational Courses which are available to residents of the Province. These courses for tradesmen include Machine Shop Practice and Radio Theory and Practice; the fee is $10.00 a course. Further information and application forms can be obtained from:

The Director,
Correspondence Courses Branch,
Department of Education,
206 Huron St.,
Toronto 5, Ont.

Training Center for Experimental Aerodynamics

The T.C.E.A., which was set up in 1956 at Rhode-Saint-Genese, Belgium, for the use of NATO nations, is inviting applications for its One-year Diploma Course in Experimental Aerodynamics for the year October 1959 to July 1960. The course is open to suitably-qualified graduate engineers and scientists, who must be fluent in either English or French. There are no fees for the course and there are a number of student fellowships to cover living expenses.

Application forms and further details can be obtained from C.A.I. Headquarters or from:

The Director,
Training Center for Experimental Aerodynamics,
72, Chaussee de Waterloo,
Rhode-Saint-Genese,
Belgium.

Applications must be filed by the 18th April, 1959.

rs of
xperi-
ndus-
st In-
nton,

have
inter-
cipate
icants
ation,
must
es are
ng in-
hools
ost of
rebate
ourses
Eng-
ingual.
Man-
a Ltd.,